

W. Mine Bureau

Bulletin 111

Mineral Technology 15

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

MOLYBDENUM; ITS ORES AND THEIR
CONCENTRATION

WITH A DISCUSSION OF

MARKETS, PRICES, AND USES

TN

23

44

no. 01

ENGINEERING

ENGIN. STORAGE

BY

FREDERICK W. HORTON



WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

311

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

MOLYBDENUM; ITS ORES AND THEIR
CONCENTRATION

WITH A DISCUSSION OF

MARKETS, PRICES, AND USES

BY

FREDERICK W. HORTON



143220
6/7/17

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

The Bureau of Mines, in carrying out one of the provisions of its organic act—to disseminate information concerning investigations made—prints a limited free edition of each of its publications.

When this edition is exhausted, copies may be obtained at cost price only through the Superintendent of Documents, Government Printing Office, Washington, D. C.

The Superintendent of Documents is *not an official of the Bureau of Mines*. His is an entirely separate office, and he should be addressed:

SUPERINTENDENT OF DOCUMENTS,
Government Printing Office,
Washington, D. C.

The general law under which publications are distributed prohibits the giving of more than one copy of a publication to one person. The price of this publication is 30 cents.

First edition. October, 1916.

CONTENTS.

	Page.
Introduction.....	3
Scope and purpose of investigation.....	4
Present condition of the molybdenum industry.....	4
The future of the molybdenum industry.....	5
Acknowledgments.....	5
Part I. The molybdenum minerals.....	7
Molybdenite.....	7
Tests for molybdenite.....	8
Occurrences of molybdenite.....	8
Accompanying minerals.....	9
Jordisite.....	9
Wulfenite.....	9
Tests.....	10
Occurrence and accompanying minerals.....	10
Molybdite.....	11
Tests for molybdite.....	12
Occurrence and accompanying minerals.....	12
The rare molybdenum minerals.....	12
Ilsemannite.....	12
Belonesite.....	13
Tests.....	13
Powellite.....	13
Tests.....	14
Occurrence.....	14
Pateraite.....	14
Achrematite.....	14
Tests.....	14
Eosite.....	14
Tests.....	15
A new molybdenum mineral.....	15
Doubtful species.....	16
Physical properties of molybdenum.....	17
Chemical properties of molybdenum.....	19
Uses of molybdenum.....	20
Molybdenum steels.....	21
Manufacture of molybdenum steels.....	22
Use of molybdenum in tool steels.....	22
Use of molybdenum in magnet steel.....	25
Use of molybdenum in acid-resisting steels.....	25
Use of molybdenum in other alloy steels.....	25
Ferromolybdenum.....	26
Use of molybdenum in stellite.....	26
Uses of metallic molybdenum.....	27
Use of molybdenum in chemicals.....	28
Production of molybdenum ores.....	29
Queensland.....	29
New South Wales.....	30
Norway.....	31

Part I. The molybdenum minerals—Continued.	
Production of molybdenum ores—Continued.	Page.
United States.....	32
Canada.....	34
Imports of molybdenum.....	34
Market for molybdenum.....	35
How molybdenum concentrates are marketed.....	36
Prices of molybdenite and of wulfenite concentrates.....	37
Qualitative tests for molybdenum.....	40
Quantitative determination of molybdenum.....	41
Solution.....	41
Precipitation.....	42
Conversion of precipitate to weighable form.....	43
Volumetric determination of precipitated molybdenum trisulphide.....	43
Method adopted by the Bureau of Mines.....	44
Part II. Description of deposits.	45
General distribution of deposits.....	45
Arizona.....	45
Wulfenite at the Mammoth and Collins mines, Pinal County.....	46
Wulfenite at the Old Yuma mine, Pima County.....	48
Other occurrences of wulfenite in Arizona	50
Occurrence of molybdenite at the Leviathan mines, Mohave County.....	52
Molybdenite at the Smith & Sawyer and the Miller claims, Mohave County.....	55
Molybdenite property of Arizona Molybdenum Co., Pima County.....	55
Molybdenite at Leader mine, Pima County.....	56
Other occurrences of molybdenite.....	57
California.....	58
Molybdenite at property of Santa Maria Molybdenum Mining & Milling Co., San Diego County.....	60
Molybdenite near Bishop, Inyo County.....	61
Molybdenite at the Buchanan prospect, Fresno County.....	62
Molybdenite near Corona, Riverside County.....	62
Molybdenite near California Hot Springs, Tulare County.....	62
Molybdenite at Caliente, Kern County.....	63
Colorado.....	63
Molybdenite mine of Primos Chemical Co., near Empire.....	64
Salamander and Blue Valley molybdenite claims, near Breckenridge, Summit County.....	67
Molybdenite on Bartlett Mountain, Summit County.....	68
Molybdenite near Ophir, San Miguel County.....	69
Other occurrences of molybdenite in Colorado.....	70
Deposit near Robinson, Summit County.....	70
Deposit near Nathrop, Chaffee County.....	70
Prospect near Parkdale, Fremont County.....	70
Specimens from Westcliffe, Custer County.....	71
Claim near Marble, Gunnison County.....	71
Deposit south of Aspen, Pitkin County.....	71
Claims near Kokomo, Summit County.....	72
Property near St. Cloud, Larimer County.....	72
Montana.....	72
Molybdenite near Chico Hot Springs, Park County.....	73
Molybdenite in Carpenter Gulch, Powell County.....	75
Other molybdenite occurrences in Montana.....	76
Wulfenite ore near Twin Bridges, Madison County.....	76

CONTENTS.

V

	Page.
Part II. Description of deposits—Continued.	
New Mexico.....	77
Molybdenite property of the Romero Mining Co.....	78
Washington.....	79
Crown Point mine.....	79
Molybdenite near Loomis, Okanogan County.....	83
Other occurrences of molybdenite in Washington.....	84
Deposit near Safety Harbor Creek, Chelan County.....	84
Deposit on Sheep Mountain, Okanogan County.....	84
Prospects near Oroville, Okanogan County.....	85
Miscellaneous occurrences.....	85
Tabulation of molybdenite and of wulfenite occurrences in the United States.....	86
Part III. Concentration.	91
Importance of successful concentration of low-grade ores.....	91
Concentration of molybdenite ores.....	92
Rolling and screening processes.....	93
Electrostatic processes.....	94
Principles of separation.....	94
Range of application.....	95
Description of separators.....	96
Concentration tests.....	97
Suggested method for treatment of a typical ore.....	99
Flotation processes.....	101
Water-flotation processes.....	102
Character of water flotation.....	102
Necessary factors in successful water flotation.....	102
Results of tests with Wood's process.....	103
Oil-flotation processes.....	105
Results with Elmore vacuum flotation.....	107
Removal of accompanying metallic sulphides.....	108
Summary.....	109
Concentration of wulfenite ores.....	110
Concentration tests of wulfenite ore from Old Yuma mine, near Tucson, Ariz.....	111
Discussion of results of tests.....	113
Boykin & Hereford wulfenite mill at Mammoth, Ariz.....	115
Discussion of flow sheet.....	116
Results of screen test.....	119
Selected bibliography on molybdenum.....	121
Publications on mineral technology.....	126

ILLUSTRATIONS.

	Page.
PLATE I. <i>A</i> , Molybdenite crystal from Crown Point mine, Railroad Creek, Chelan County, Wash.; <i>B</i> , Another molybdenite crystal from Crown Point mine.....	8
II. <i>A</i> , Molybdenite crystal from near Buena Vista, Colo.; <i>B</i> , Flake from molybdenite crystal showing alteration to molybdite, from Santa Maria property, San Diego County, Cal.....	8

	Page.
PLATE III. <i>A</i> , Molybdenite on quartz from Crown Point mine, Railroad Creek, Chelan County, Wash.; <i>B</i> , Wulfenite crystals lining geode from Mammoth mine, Pinal County, Ariz.	8
IV. <i>A</i> , Wulfenite crystals from Yuma County, Ariz.; <i>B</i> , Wulfenite crystals from Lucky Bill mine, near Santa Rita, N. Mex., showing unusual forms.	10
V. <i>A</i> , Wulfenite crystals from Eureka, Nev.; <i>B</i> , Molybdite crystals on iron-stained granite from Santa Maria, San Diego County, Cal.	10
VI. Map of the vicinity of Mammoth, Ariz.	46
VII. <i>A</i> , Buildings and dumps of Mammoth and Collins mines, Schultz, Ariz.; <i>B</i> , Crystallized wulfenite in lead carbonate from Mammoth mine, Schultz, Ariz.	46
VIII. <i>A</i> , Near view of outcrop of Whale vein, Copper Canyon, near Copererville, Ariz.; <i>B</i> , Outcrop of Whale vein, looking south.	52
IX. <i>A</i> , Section through typical ore from Whale vein, Copper Canyon, near Copererville, Ariz.; <i>B</i> , Section of typical molybdenite ore from Leader mine, Helvetia, Ariz.	52
X. <i>A</i> , Outcrop of dike on Santa Maria property, San Diego County, Cal., looking northwest; <i>B</i> , Outcrop of low-grade molybdenite ore at Primos mine near Empire, Colo.	60
XI. <i>A</i> , Molybdenite in iron-stained granite from Santa Maria property, San Diego County, Cal.; <i>B</i> , Molybdenite in granite from John Fletcher quarry, near Corona, Cal.	60
XII. <i>A</i> , Section through typical molybdenite ore from Primos mine near Empire, Colo.; <i>B</i> , Typical molybdenite ore from Bartlett Mountain, Summit County, Colo.	64
XIII. <i>A</i> , View of Red Mountain, near Empire, Colo.; <i>B</i> , Section through typical molybdenite ore from Great Western mine, near Chico, Park County, Mont.	64
XIV. Map of part of Summit County, Colo., showing location of molybdenite deposits on Quandary, Bartlett, and Chalk Mountains.	66
XV. <i>A</i> , Typical molybdenite ore from Salamander claim, Quandary Peak, Summit County, Colo.; <i>B</i> , Scraping tailings for retreatment to recover wulfenite, Mammoth, Ariz.	66
XVI. <i>A</i> , Section through molybdenite ore from Quigley mine, Carpenter Gulch, near Ophir, Powell County, Mont.; <i>B</i> , Section through molybdenite ore from Romero mine, Porvenir, San Miguel County, N. Mex.	74
XVII. <i>A</i> , Outcrop of upper vein at mouth of Tunnel No. 1, Crown Point mine, Railroad Creek, Chelan County, Wash.; <i>B</i> , Lower tunnel and dump from upper workings, Starr mine, near Loomis, Okanogan County, Wash.	80
XVIII. <i>A</i> , Tailing piles containing wulfenite from stamp and cyanide mills, Mammoth, Ariz.; <i>B</i> , Boykin and Hereford wulfenite mill, Mammoth, Ariz.	114
FIGURE 1. Sketch map of the vicinity of Lake Chelan, Wash., and vicinity, showing the situation of the Crown Point and Robischand mines.	80
2. Flow sheet of Boykin & Hereford wulfenite mill, Mammoth, Ariz.	117

MOLYBDENUM; ITS ORES AND THEIR CONCENTRATION.

By FREDERICK W. HORTON.

INTRODUCTION.

With large deposits of low-grade molybdenum ore and a latent market for molybdenum, which with development might perhaps equal that for tungsten, the United States has for years made no production of molybdenum ore worthy of mention. In fact, during the decade previous to 1914, there was no output of molybdenum ore in this country except in 1905, 1906, and 1907, when a few small lots of molybdenite and wulfenite were marketed.^a

To ascertain why this possible source of economic wealth should remain undeveloped, the United States Bureau of Mines undertook an investigation in 1914, with a view of assisting the establishment of a molybdenum industry in this country. A preliminary review of the situation showed the following conditions:

Briefly there was a lack of any considerable demand for molybdenum for the one known use that might consume any large tonnage of it, that is, for the manufacture to certain alloy steels to which molybdenum imparts properties roughly similar to those produced by tungsten. It was at once evident that the market for molybdenum in alloy steels must be developed, or that extensive new uses for the metal must be created, before the demand would be sufficient to warrant any extensive mining of molybdenum ore.

Investigation showed that one of the chief factors in retarding the development of any demand for molybdenum by the alloy-steel trade was that manufacturers who might use, or might investigate the possibilities of using, the metal were kept out of the market by the fear of not being able to obtain steady supplies. On the other hand, those who might be interested in the development of some of the extensive low-grade molybdenite or wulfenite deposits in this country were prevented from doing so by the small visible demand and the fear that any large production would glut the market. Owing to these conditions the mining of molybdenum has in the past been confined

^a Mineral Resources U. S. for 1904 to 1913, U. S. Geol. Survey, 1905 to 1914.

almost entirely to small-scale operations on high-grade streaks of molybdenite ore, and the methods of recovery have been limited largely to cobbing and hand picking.

SCOPE AND PURPOSE OF INVESTIGATION.

The problem before the Bureau of Mines was to ascertain the character and extent of the deposits of molybdenum ore in the United States from which supplies requisite for the development of the market might be obtained, and how the ores might best be concentrated into a marketable product. These features were the ones that the investigation described in the following pages principally covered.

The direct purpose of this bulletin is, on the one hand, to prove to possible consumers of molybdenum that the element is not as rare as commonly supposed, and that this country possesses many deposits of low-grade ore from which large supplies may be derived, and on the other hand, to prove to present and prospective producers of molybdenum that there is a latent market for their product in the alloy-steel trade, which needs only the assurance of steady supplies for a considerable development. It is also intended to assist the miner of molybdenum by giving him information regarding various methods of concentration that have proven applicable to the different types of molybdenum ore, and by acquainting him with market conditions, uses, prices, etc. The various molybdenum minerals are described in detail, and tests for their determination are given to aid the prospector in recognizing them. In addition to the most applicable and reliable qualitative tests for molybdenum, the quantitative determination of the element is described in some detail, as the methods of analyses recommended in the ordinary textbooks will not in general give correct results, particularly on low-grade ores.

PRESENT CONDITION OF THE MOLYBDENUM INDUSTRY.

The unprecedented demand for steel-hardening metals occasioned by the European war is slowly drawing the attention both of prospective consumers and of producers to possibilities in regard to molybdenum. Several mining operations looking toward a considerable production of both molybdenite and wulfenite have already been commenced, and manufacturers are investigating the possibilities of using molybdenum in a large way. The fact that molybdenum is now (April 1, 1916) selling at \$3 to \$4 a pound, as compared with \$8 to \$10 a pound for tungsten, and the further fact that 1 pound of molybdenum will produce approximately the same results as 2 or 3 pounds of tungsten, are serving to quicken this interest.

Under the influence of the high prices being paid for the metal and the unusual demand, the whole molybdenum industry is developing

as never before, not only in the United States, but also in Queensland, New South Wales, and Norway, the three countries that have previously supplied practically the entire world's production. In this country, since late in 1914, a fair-sized molybdenite mine has been opened up on a low-grade deposit at Red Mountain, near Empire, Colo., and extensive shipments of ore have been made. Many molybdenite mines and prospects throughout the West have produced small lots of high-grade ore, and some of them have accumulated dumps of milling ore. A noteworthy amount of development work has been done at many of these properties, and several of them are rapidly being put into condition to become producers. Since the summer of 1914 a considerable tonnage of wulfenite concentrates of medium grade has been derived by milling operations on some large tailing piles at Mammoth, Ariz., and in the spring of 1915 the output from this source was more than doubled. It is lately reported that a mill has been installed to treat wulfenite ore from the Old Yuma mine, near Tucson, Ariz.

Developments have already progressed to such an extent that, in the author's opinion, the molybdenum production of the United States in 1915 will compare favorably with that of Queensland, New South Wales, or of Norway, and it may even exceed them.

THE FUTURE OF THE MOLYBDENUM INDUSTRY.

Of course, the extremely high prices that are now being paid for molybdenum can not last, but even under normal conditions the author sees no reason why molybdenum should not compete with tungsten in the manufacture of many alloy steels. It is surely as plentiful an element as tungsten, its ores can be mined as cheaply as those of the latter metal, and although high-grade concentrates from molybdenite ores will probably cost a little more to produce than from tungsten ores, the fact that much less molybdenum need be used to produce a given result should give it the advantage in the market. If steady supplies of molybdenum can be obtained at or near the prices at which tungsten is offered, the demand for it can not help but develop greatly within a few years.

ACKNOWLEDGMENTS.

The writer takes pleasure in acknowledging his indebtedness to Mr. Karl L. Kithil, mineral technologist of the Bureau of Mines, for his kindly advice in the preparation of this report, and to Dr. Charles L. Parsons, chief of the division of mineral technology of the bureau, for many valuable suggestions. The author's thanks are also extended to Messrs. R. B. Moore, J. C. Morgan, and H. A. Doerner, of the Denver office of the bureau, for chemical analyses, and to Dr.

F. B. Laney, of the United States Geological Survey, for photographing ore specimens and for petrographic work; also to R. E. Head, of the Salt Lake office of the bureau, for the preparation of rock sections and for assistance in concentration tests.

The writer expresses his appreciation to the following companies and individuals for their kindness in placing at his disposal the equipment of their testing laboratories for concentration work: W. G. Swart, of the American Zinc Ore Separating Co.; Henry E. Wood, president of Henry E. Wood & Co.; Albert M. Plumb, of the Plumb Jig Co.; Frank E. Shepard, president of the Denver Engineering Works Co.; and W. S. Myers, president of the Sutton, Steele & Steele Manufacturing, Mining & Milling Co., all of Denver, Colo. Acknowledgments are also made to the following individuals and companies for their courtesy in supplying the writer with molybdenum ores for concentration tests: George H. Daily, Tucson, Ariz.; R. J. A. Widmar, Breckenridge, Colo.; William Young and C. S. Lively, Empire, Colo.; H. Leal, Denver, Colo.; Smith & Sawyer, Kingman, Ariz.; Young Bros., Shultz, Ariz.; Santa Maria Molybdenum Mining & Milling Co., San Diego, Cal.; and the Grand View Mining & Development Co., Twin Bridges, Mont.

The writer's thanks are also due E. S. Dana and William E. Ford, of Yale University; Frank L. Hess, of the United States Geological Survey; John E. Wolff, of Harvard University; Charles H. Warren, of the Massachusetts Institute of Technology; George D. Merrill, of the United States National Museum; L. P. Gratacap, of the American Museum of Natural History; and Oliver C. Farrington, of the Field Museum of Natural History, for information as to occurrences of molybdenum minerals; E. R. Boericke and A. G. Pohnsdorf, of Denver, Colo., for photographs; the Colorado Bureau of Mines and A. B. Frenzel, of Denver, Colo., for the loan of specimens; and all those companies and individuals who have allowed him to examine their molybdenum properties or have otherwise aided him.

PART I. THE MOLYBDENUM MINERALS.

The following table lists the known molybdenum minerals and gives their theoretical composition, and the percentage of molybdenum each mineral contains as based on this composition:

Molybdenum minerals.

Mineral.	Composition.	Per cent molybdenum.	Mineral.	Composition.	Per cent molybdenum.
Molybdenite ^a	MoS ₂	59.95	Powellite.....	CaMoO ₄	47.98
Wulfenite.....	PbMoO ₄	26.15	Pateraite.....	CoMoO ₄	43.84
Molybdite.....	Fe ₂ O ₃ MoO ₃ ? H ₂ O.....	39.63	Achrematite.....	3(3Pb ₂ As ₂ O ₈ PbCl ₂) 4= (Pb ₂ MoO ₅).....	3.40
Ilsemannite ^b	MoO ₂ 4MoO ₃ (?).....	68.18	Eosite.....	Vanado-molybdate of lead.....	
Belonesite.....	MgMoO ₄	52.08			

^a An amorphous variety of molybdenite called jordisite is said to exist (see p. 9.)

^b Composition doubtful (see p. 12.).

Of the above list only the first two minerals, molybdenite and wulfenite, have thus far proved of commercial importance. With the exception of molybdite, the other minerals listed are rare and are to be considered only in the light of interesting mineralogical occurrences. Besides these there are other molybdenum minerals that have been reported, but information concerning them is so incomplete both as regards occurrence and composition that their existence as definite species can not be considered as authenticated. (See p. 12.)

MOLYBDENITE.

Molybdenite is the disulphide of molybdenum (MoS₂) and contains 59.95 per cent of molybdenum and 40.05 per cent of sulphur. It is a soft, opaque, lead-gray mineral with a metallic luster and greasy feel. It commonly occurs in flakes or scales having a prominent basal cleavage and resembling some micas in the way the flakes may be split into thin leaves. Finely granular and massive forms are also common. The mineral is sectile and in the flaky form the laminæ are flexible but not elastic. In hardness it ranges from 1 to 1.5, being so soft that it soils the fingers readily in handling and marks paper, on which it leaves a bluish-gray trace. On porcelain its streak is slightly greenish. Its specific gravity has been variously determined at 4.7 to 4.8.^c

^c Dana, E. S., A system of mineralogy, 6th ed., 1911, p. 41.

On account of many similar characteristics molybdenite is often confused with graphite, but it may be easily distinguished from the latter as graphite has a much lower specific gravity, 2.09 to 2.23, and its streak is lead-gray on both paper and porcelain. Heating a fragment of the mineral in a closed tube will conclusively settle any further question as to its identity, as the strong sulphurous odor given off by molybdenite is entirely lacking with graphite.

Molybdenite crystallizes in hexagonal form and the crystals are tabular or short and slightly tapering prisms. The prismatic planes are horizontally striated and on the base of some crystals there are striae normal to the edges. In Plate I, which illustrates characteristic forms of molybdenite crystals, the horizontal striae on the prismatic faces may readily be seen. Many molybdenite aggregates exhibit a distinct radial formation. This typical structure is well shown in Plate II, A. A typical molybdenite ore is shown in Plate III, A.

An artificial crystallized molybdenite with a specific gravity of 5.06 has been made by melting together potassium carbonate, sulphur, and molybdic oxide in a platinum crucible.^a

Molybdenite commonly alters to molybdate, but it is also reported as sometimes altering to ilsemannite. (See pp. 12 and 13.)

TESTS FOR MOLYBDENITE.

Different methods of testing molybdenite follow:^b When heated in an open tube molybdenite gives off sulphurous fumes, and a pale yellow crystalline sublimate of molybdenum trioxide (MoO_3) is formed. Before the blowpipe, the mineral is infusible and imparts a yellowish-green color to the flame. On charcoal in the oxidizing flame, pulverized molybdenite gives a strong odor of sulphur and the charcoal is coated with crystals of molybdic oxide which appears yellow while hot and white when cold. Near the heated mineral the coating is copper-red, and if the white coating is touched with an intermittent reducing flame, it becomes a beautiful azure blue. Molybdenite is decomposed by nitric acid, leaving a white or grayish residue (molybdic oxide).

OCCURRENCES OF MOLYBDENITE.

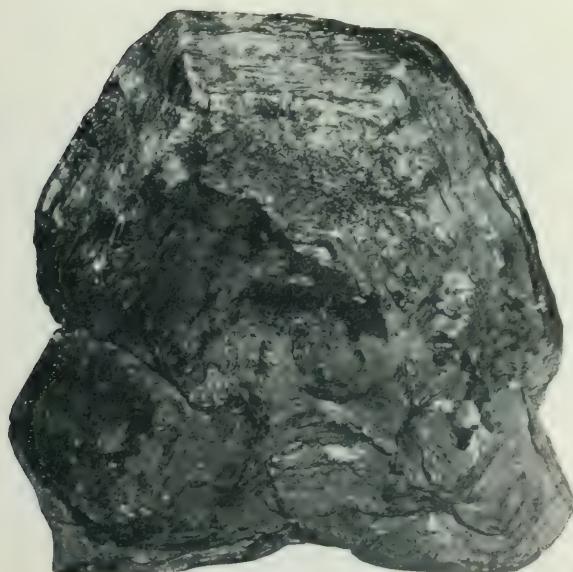
Probably three-fourths of the reported occurrences of molybdenite are in acid igneous rocks such as granites, pegmatites, trachytes, and syenites. Next in order of importance as regards deposits of the mineral are the metamorphic rocks, molybdenite being found in serpentines and gneisses, and in amphibolite, chlorite, talc, and mica schists, etc. Next follow the sedimentary rocks with occur-

^a Dana, E. S., op. cit., p. 42.

^b Dana, E. S., op. cit., p. 41.



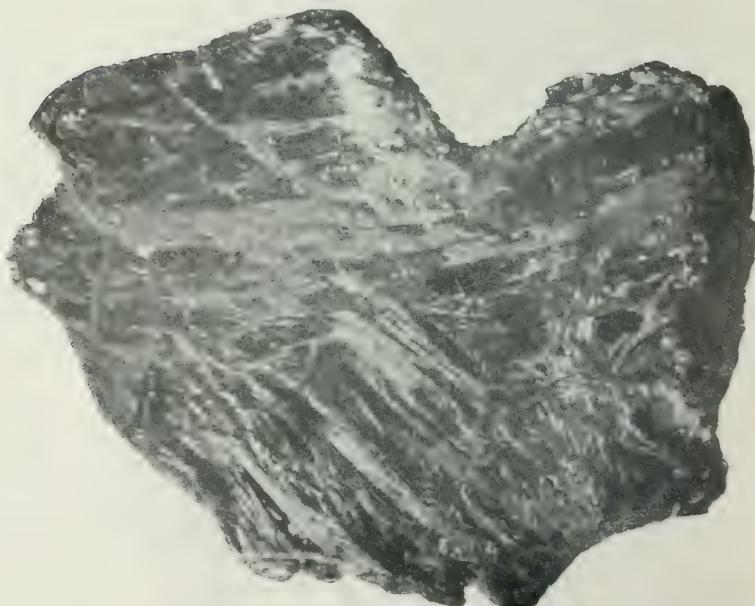
A1. MOLYBDENITE CRYSTAL FROM CROWN POINT MINE, RAILROAD CREEK,
CHELAN COUNTY, WASH. (TWO-THIRDS NATURAL SIZE.)



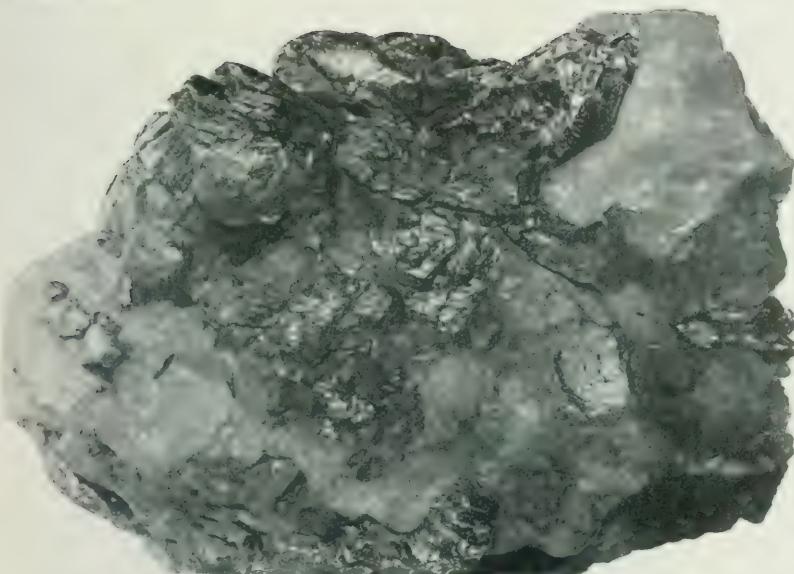
B. ANOTHER MOLYBDENITE CRYSTAL FROM CROWN POINT MINE.
(ONE AND ONE-HALF TIMES NATURAL SIZE.)



I. MOLYBDENITE CRYSTAL FROM NEAR BUENA VISTA, COLO. (ONE AND ONE-HALF TIMES NATURAL SIZE.)



II. FLAKE FROM MOLYBDENITE CRYSTAL SHOWING ALTERATION TO MOLYBDITE, FROM SANTA MARIA PROPERTY, SAN DIEGO COUNTY, CAL. (FOUR TIMES NATURAL SIZE.)



A. MOLYBDENITE ON QUARTZ FROM CROWN POINT MINE, RAILROAD CREEK, CHELAN COUNTY, WASH. (THREE-FIFTHS NATURAL SIZE.)



B. WULFENITE CRYSTALS LINING GEODE FROM MAMMOTH MINE, PINAL COUNTY, ARIZ. (ONE-HALF NATURAL SIZE.)



rences of the mineral in conglomerates and limestones, and finally the basic igneous rocks with a few deposits in gabbros, basalts, etc.

Localities in the United States where molybdenite has been reported are named in part 2 of this report, and detailed descriptions of many characteristic occurrences are given there.

ACCOMPANYING MINERALS.

Besides the occurrence of gold and of various silver minerals with molybdenite, the author has noted the following accompanying minerals: Molybdite, bornite, chalcopyrite, malachite, azurite, chrysocolla, native copper, pyrite, galena, pyrrhotite, magnetite, limonite, sphalerite, bismuthinite, cassiterite, wolframite, scheelite, calcite, quartz, orthoclase, pyroxene, hornblende, garnet, epidote, tourmaline, muscovite, and biotite. The following additional minerals have been recorded by Crook^a as associated with molybdenite: Arsenopyrite, fluorite, barite, apatite, rutile, oligoclase, tremolite, scapolite, and zircon; and Umpleby^b has noted tetrahedrite, chalcocite, cuprite, hubnerite, and manganese oxides as accompanying minerals. Dolomite, talc, beryl, phlogophite, and löllingite are also mentioned by Hintze^c as occurring with molybdenite.

JORDISITE.

According to Cornu,^d there exists a black powdery form of molybdenum sulphide that he considers to be distinct from crystalline molybdenite. It is described as "colloidal molybdenum sulphide," and is said to alter to ilsemannite^e and to occur at Himmelfurst, Freiberg, Saxony. Jordisite is listed as a variety of molybdenite by Cahen and Woottton.^e

WULFENITE.

Wulfenite is a molybdate of lead ($PbMoO_4$) and theoretically contains 26.15 per cent of molybdenum and 56.42 per cent of lead. It is a heavy, brittle, subtransparent to subtranslucent mineral with a resinous or adamantine luster and is generally of a wax or orange-yellow color. It may, however, be siskin and olive green, yellowish-gray, brown, grayish-white to nearly colorless, or orange to bright red. Its hardness is 2.75 to 3 and its specific gravity is 6.7 to 7. It has a subconchoidal fracture and a white streak. In planes parallel with its crystal pyramid faces it has a smooth cleavage, but in other

^a Crook, A. R., Bull. Geol. Soc. America, vol. 15, 1904, pp. 283-288.

^b Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, 1913, p. 73.

^c Hintze, Carl, Handbuch der Mineralogie, Bd. 1, pp. 410-418.

^d Cornu, F., Natürliches kolloides Molybdänsulfid (Jordisit): Ztschr. Chem. Ind. Kolloide, Bd. 4, 1909, p. 190.

^e Cahen, Edward, and Woottton, W. O., The mineralogy of the rarer metals; a handbook for prospectors 1912, pp. 51-52.

directions the cleavage is less distinct. It crystallizes in the tetragonal system with pyramidal hemihedrism. The crystals are commonly square and tabular and are sometimes extremely thin, with a vicinal pyramid replacing the basal plane. Less frequently the crystals are octahedral or prismatic, the prismatic faces showing the hemihedrism characteristic of the mineral. Plates III, B, and IV, A, illustrate common tabular forms of wulfenite crystals and Plate V, A, shows a fine specimen illustrating the extremely thin crystals referred to above. Wulfenite crystals of mineral form are illustrated in Plate IV, B.

Wulfenite generally occurs in well-crystallized forms, but it is also found in coarse-grained or fine-grained masses. Small percentages of calcium, chromium, vanadium, copper, iron, or aluminum are generally present in wulfenite as impurities.

Among others, the following characteristic analyses of American wulfenites are given by Dana:^a

Characteristic analyses of American wulfenites.

Source of sample.	Per cent MoO ₃ .	Per cent PbO.	Per cent other oxides.	Total per cent.
Eureka County, Nev.	39.33	61.11	1.04 CaO ₃ , 0.38 Fe ₂ O ₃	101.86
Phoenixville, Pa.	39.21	60.00	.38 Cr ₂ O ₃	99.59
Do.	37.47	60.30	1.28 V ₂ O ₅	99.05

TESTS.^b

Before the blowpipe wulfenite decrepitates and fuses below 2. With borax in the oxidizing flame it gives a colorless glass which in the reducing flame becomes an opaque black or dirty green with black flocks. With salt of phosphorus in the oxidizing flame wulfenite gives a yellowish-green glass which becomes dark green in the reducing flame. The powdered mineral, when heated with soda on charcoal, yields metallic lead. On evaporation with hydrochloric acid wulfenite is decomposed, forming lead chloride and molybdic oxide. Moistening the residue with water and adding metallic zinc gives an intense blue color which persists after dilution.

OCCURRENCE AND ACCOMPANYING MINERALS.

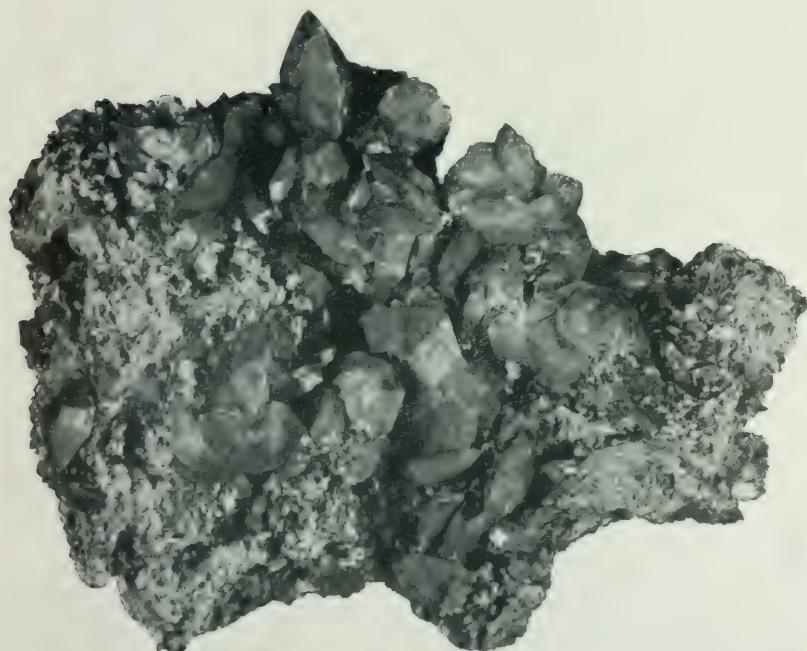
Deposits of wulfenite are confined almost wholly to veins, in which it occurs associated with other lead minerals. Localities in the United States where wulfenite has been reported are named in part 2, and detailed descriptions of several characteristic occurrences are also given.

^a Dana, E. S., *A system of mineralogy*, 6th ed., 1911, p. 991.

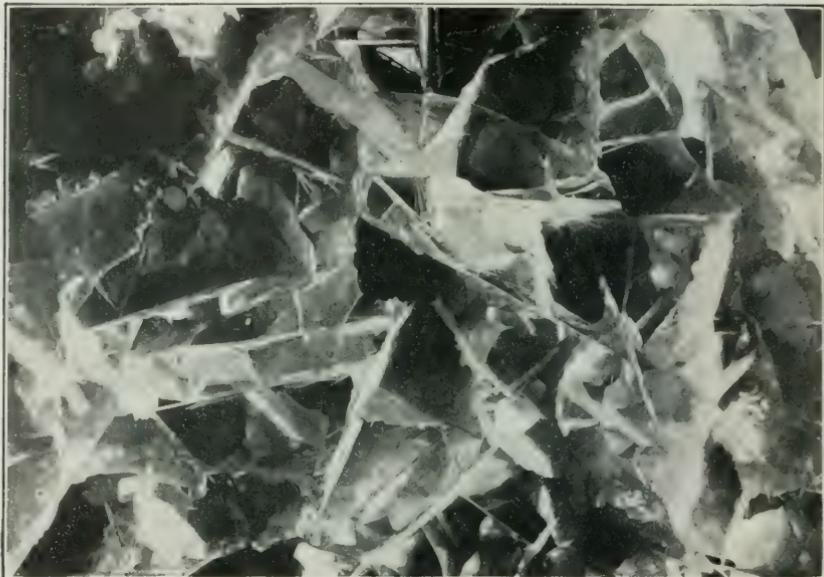
^b Dana, E. S., *loc. cit.*



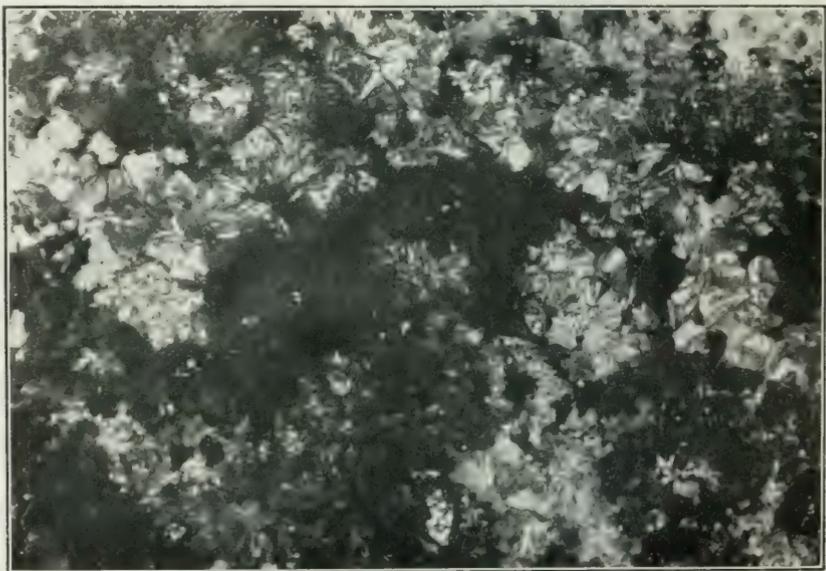
A. WULFENITE CRYSTALS FROM YUMA COUNTY, ARIZ. (NATURAL SIZE.)



B. WULFENITE CRYSTALS FROM LUCKY BILL MINE, NEAR SANTA RITA, N. MEX., SHOWING UNUSUAL FORMS. (ONE AND ONE-FOURTH TIMES NATURAL SIZE.)



A. WULFENITE CRYSTALS FROM EUREKA, NEV. (NATURAL SIZE.)



B. MOLYBDITE CRYSTALS ON IRON-STAINED GRANITE FROM SANTA MARIA, SAN DIEGO COUNTY, CAL. (THREE TIMES NATURAL SIZE.)

Outside of the gangue-forming minerals, wulfenite has been found associated with gold and various silver minerals, with galena, cerussite, pyromorphite, vanadinite, anglesite, and descloizite. In connection with the occurrence of gold with wulfenite, it may be of interest to note that the native gold is sometimes contained directly in the wulfenite crystals themselves. (See p. 115.)

MOLYBDITE.

Molybdite is a hydrous ferric molybdate ($\text{Fe}_2\text{O}_3 \cdot 3\text{MoO}_3 \cdot 7\frac{1}{2}\text{H}_2\text{O}$) and theoretically contains 39.63 per cent of molybdenum. It is a lemon-yellow to pale-yellow mineral, and occurs as an earthy powder, incrustations, fibrous masses, or capillary crystals in radiating groups. The crystals and many of the fibrous forms of the mineral have a silky luster. Molybdite is an alteration product of molybdenite, probably formed by the interaction of molybdic acid (liberated by the oxidation of the molybdenite) and limonite. The formation of the limonite in many cases may have resulted from the weathering of pyrite, which is commonly associated with the molybdenite, simultaneously with or previous to the weathering of the molybdenite.

Plate V, *B*, illustrates a group of molybdite crystals, showing their capillary form and characteristic grouping in radiating clusters. Plate II, *B*, shows a flake from a large crystal of molybdenite, with molybdite extensively developed along its cleavage planes.

For many years the erroneous idea has existed that molybdite agrees in composition with the artificial molybdic trioxide obtained by oxidizing molybdenite. The present textbooks on mineralogy almost universally persist in this error, giving the composition of molybdite as MoO_3 , and stating that the pure mineral contains 66.7 per cent of molybdenum. That such is not the case was first called to the author's attention by chemical tests of a sample of molybdite which from microscopic examination seemed to be practically pure. The presence of a large percentage of iron was determined, and the same result obtained from tests on other samples of molybdite from different localities led the author to believe that the iron was an essential part of the mineral. A search of the literature on molybdite revealed the fact that Schaller ^a had not only proved the presence of combined iron in molybdite, but had definitely established its composition as $\text{Fe}_2\text{O}_3 \cdot 3\text{MoO}_3 \cdot 7\frac{1}{2}\text{H}_2\text{O}$.

His analyses of molybdite from different localities in the United States, given in the accompanying table, have the insoluble matter deducted and are recalculated to 100 per cent. The last column of

^a Schaller, W. T., Mineralogical notes—series 1: U. S. Geol. Survey Bull. 490, 1911, pp. 84-92.

the table gives the theoretical analysis as calculated from the formula $\text{Fe}_2\text{O}_3\text{MoO}_3 \cdot 7\frac{1}{2}\text{H}_2\text{O}$. Attention is called to the close agreement of the analysis of the molybdite from New Hampshire with this calculated analysis.

Analyses of molybdite.

Constituent.	Telluride, Colo.	Hortense, Colo.	Califor- nia.	New Hamp- shire.	Calcu- lated from formula.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
H_2O	16.8	20.19	19.5	18.28	18.57
Fe_2O_3	20.2	20.30	20.0	21.87	22.01
MoO_3	63.0	59.42	60.5	59.85	59.42
	100.00	100.00	100.0	100.00	100.00

The specific gravity of the molybdite from Hortense, Colo., is given by Schaller as 2.99.

TESTS FOR MOLYBDITE.

Regarding tests of molybdite, Schaller ^a writes as follows:

On heating the mineral in a closed tube abundant water is easily given off and the mineral assumes a dark-olive color; on further heating it again becomes lighter in color. On heating the mineral in a crucible the color changes are very marked. At first the yellow mineral darkens and becomes a dark gray, appearing almost black and with slight olive tint, then it becomes a light yellow again, and on further heating changes to a deep orange color. If the mineral now be allowed to cool, the orange changes to yellow and back to orange again on reheating. If the dark-colored material be allowed to cool, it retains its dark gray color, and on reheating passes through yellow to the orange. On heating for some time at a higher temperature, the mineral, on cooling, becomes a permanent bright green. By further heating all of the molybdenum is volatilized and the dark-red ferric oxide remains. The mineral is readily soluble in hydrochloric acid, and is decomposed by ammonia, taking on a brown color (probably due to the separating ferric hydroxide). After a while, all the molybdenum of the mineral goes into solution, leaving the insoluble ferric hydroxide.

OCCURRENCE AND ACCOMPANYING MINERALS.

As molybdite is an alteration product of molybdenite, its occurrences and associated minerals are practically the same as those of the latter mineral. (See p. 11.)

THE RARE MOLYBDENUM MINERALS.

ILSEMANNITE.

Ilsemannite ^b is an oxide of molybdenum said to result from the decomposition of metallic molybdates and is probably identical with the artificial compound $\text{MoO}_2 \cdot 4\text{MoO}_3$. It is a blue-black to black cryptocrystalline mineral, and has been reported as occurring in

^a Schaller, W. T., op. cit., pp. 85-86.

^b Dana, E. S., A system of mineralogy, 6th ed., 1911, p. 202.

barite and associated with wulfenite at Bleiberg, in Corinthia. It is soluble in water, giving a deep blue solution which on evaporation yields dark-blue crystals. Lindgren and Ransome^a state that material from a quartz vein carrying molybdenite, pyrite, and sphalerite and situated a short distance east of the Howard flat vein in the Cripple Creek District, Colo., upon exposure to the sun and air, turns yellow or green and finally a deep Prussian blue. Little tufts of yellow material are formed on the specimens and occasionally coatings of a dark-blue mamillary substance. "The yellowish material is believed to be molybdite." "The blue substance, which dissolves in water and is associated with some ferrous sulphate, also contains a large amount of molybdenum, and probably is the rare mineral ilsemannite (MoO_4MoO_3)."

BELONESITE.

Belonesite^b is regarded as magnesium molybdate (MgMoO_4). It is a white transparent mineral occurring in minute acicular crystals of the tetragonal system, and theoretically contains 52.08 per cent of molybdenum. It occurs in rock fragments enveloped in the Vesuvian lava of 1872.

TESTS.

Before the blowpipe belonesite fuses with difficulty. It dissolves readily in salt of phosphorus, but less easily in the borax bead, and is insoluble in acids.

POWELLITE.

Powellite is calcium molybdate (CaMoO_4), which when pure contains 47.98 per cent of molybdenum. It is a dull-gray color, and according to Schaller^c has a specific gravity of approximately 4.25. It is a pseudomorph after molybdenite, often preserving the structure of the latter mineral and occurring in platy masses. Dana^d states that calcium tungstate is present in the mineral and quotes an analysis showing 10.28 per cent WO_3 . Schaller, however, calls attention to the fact that any calcium tungstate present exists as a mechanical mixture of scheelite with the mineral and states that "The association of molybdenite with scheelite is well known, and when the molybdenite alters to powellite the association of powellite with scheelite necessarily follows. The agencies affecting the change from molybdenum sulphide to calcium molybdate are apparently without effect on the scheelite."

^a Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colo.: U. S. Geol. Survey, Prof. Paper No. 54, 1906, p. 124.

^b Dana, E. S., op. cit., p. 992.

^c Schaller, W. T., Mineralogical notes—series I: U. S. Geol. Survey, Bull. 490, 1911, pp. 80-83.

^d Dana, E. S., op. cit., p. 989.

TESTS.

The mineral fuses at about 5 to a gray mass. It reacts for molybdenum with salt of phosphorus and is decomposed by nitric and hydrochloric acids.^a

OCCURRENCE.

Powellite has been found in the United States in the Peacock lode of the Seven Devils mining district in western Idaho, where it is associated with argentiferous bornite and dark-brown garnet;^a at the South Hecla copper mine, Houghton County, Mich., where it occurs in fine crystals;^b near Oak Springs, Nye County, Nev.;^c and Baringer Hill, Llano County, Tex.^d

PATERAITE.

Pateraite^e is supposed to be cobalt molybdate (CoMoO_4). It occurs as an impure massive mineral of black color associated with uranium in the Elias mine, Joachimisthal, Austria.

ACHREMATITE.

Achrematite^f is a massive, crypto-crystalline mineral with the formula $3(3\text{Pb}_3\text{As}_2\text{O}_8\text{PbCl}_2)4(\text{Pb}_2\text{MoO}_5)$ and contains 3.40 per cent of molybdenum. It has an uneven to subconchoidal fracture, is brittle, has a hardness of 3 to 4, and a specific gravity of about 6. In color it is sulphur-yellow to orange and red, but in mass is liver-brown, owing to admixed limonite. Its streak is pale cinnamon-brown; its luster is resinous to adamantine and fragments of the mineral are translucent on thin edges. It occurs at the mines of Guanacere, Chihuahua, Mexico.

TESTS.

Before the blowpipe it decrepitates slightly, turning a dark brick red and fusing easily to a nearly black globule which shows indistinct crystalline facets on cooling. On charcoal it yields arsenical odors, a lead coating, and finally globules of lead

EOSITE.

Eosite^g is supposed to be a vanado-molybdate of lead. Its exact composition is not considered as definitely established, although Gin^h

^a Dana, E. S., A system of mineralogy, 6th ed., 1911, p. 989.

^b Dana, E. S., op. cit., appendix I, p 55.

^c Schaller, W. T., Mineralogical notes—series 1: U. S. Geol. Survey, Bull. 490, 1911, pp. 80-83.

^d Schaller, W. T., loc. cit.

^e Dana, E. S., op. cit., pp. 991-992.

^f Dana, E. S., op. cit., p. 992.

^g Dana, E. S., loc. cit.

^h Gin, G., A memoir on the methods of treatment of simple and complex ores of molybdenum, tungsten, uranium, and vanadium: Trans. Am. Elec. Chem. Soc., vol. 12, 1907, p. 412.

gives its formula as $Pb_3V_2MoO_{16}$. It occurs in minute square octahedral crystals of the tetragonal system which are found implanted on pyromorphite and cerussite at Leadhills, Scotland. It has a hardness of 3 to 4, and a brownish, orange-yellow streak. In color it is deep aurora-red.

TESTS.^a

When heated in a closed tube, eosite darkens, but regains its color on cooling. When fused with potassium bisulphate it gives a mass that is slightly yellow while hot, but on cooling turns first reddish-brown, and finally a brownish orange-yellow. This mass, dissolved in water and boiled with metallic tin, colors the solution a faint greenish-blue. Eosite is not so rapidly attacked by hydrochloric acid as wulfenite or crocoite. When a splinter of the mineral is placed on a glass plate and treated with hydrochloric acid, with the subsequent addition of alcohol, and then gently evaporated, a blue to bluish-green coating is formed with a green precipitate on the edges.

A NEW MOLYBDENUM MINERAL.

F. B. Laney, of the United States Geological Survey, recently discovered a dark-green mineral rich in molybdenum, which occurs as an incrustation on specimens of ore from Vein No. 21 of the Lucania Tunnel, near Idaho Springs, Colo. Dr. Laney's examination of the occurrence, made in conjunction with the author, showed that the mine water, which percolated slowly from the vein in the immediate neighborhood of the green incrustations, contained a molybdenum compound that colored it a deep blue. This color was so intense that in several experiments in which the mine water was used as a writing fluid the writing was as legible as with an ordinary ink. The acidity of the water was pronounced, and in some places where it had dripped upon the iron mine rails it had eaten them to a depth of three-quarters of an inch or more.

An analysis of a sample of this water by R. C. Wells, of the United States Geological Survey, showed the following results:

Analysis of mine water from Vein 21, Lucania Tunnel, Idaho Springs, Colo.^b

Substance.	Grams per liter.	Substance.	Grams per liter.
Molybdenum trioxide (MoO_3).....	7.98	Magnesium.....	0.73
Molybdenum dioxide (MoO_2).....	Trace.	Sodium.....	.26
Ferrous iron.....	2.01	Potassium.....	.14
Ferric iron.....	1.75	Sulphate (SO_4).....	18.26
Aluminum.....	.27	Chlorine (Cl).....	.17
Calcium.....	.50	Hydrogen (of free acid).....	.13

^a Dana, E. S., loc. cit.

^b The specific gravity of this water at 25° C. was 1.031.

There is no doubt that the color of the water is due to a dissolved molybdenum blue, possibly ilsemannite, but just what the compound is has not been determined.

The blue mine water had impregnated considerable areas of the vein material in the drift on both sides of the main tunnel and immediately adjoining it. The rock was colored a light blue with the coloring particularly strong along the fractures in the vein material and in the more porous rock. Where the rock carrying the molybdenum blue had been exposed to the air circulating along the main tunnel and about the mouths of the drifts there was a powdery incrustation of the dark-green molybdenum mineral already referred to. Several specimens were collected where this incrustation was a yellowish or golden green and a few where it was almost a bright yellow. On the dump at the mouth of the main tunnel many specimens were coated with the green molybdenum mineral. The latter had seemingly been formed by the action of the air on ore that had been impregnated with the molybdenum blue.

Owing to the difficulty of obtaining reasonably pure samples of these blue and green minerals, and to the inherent difficulties in the analysis of compounds, whose state of oxidation is so unstable, their exact composition has not as yet been determined.

The molybdenum minerals described above are probably identical with those noted by Lindgren and Ransome^a in a small vein east of the Howard flat vein in the Cripple Creek district, Colorado. However, the author believes that the green molybdenum mineral (relatively insoluble) is formed from the soluble blue compound, and not vice versa, as indicated by Lindgren and Ransome.

DOUBTFUL SPECIES.

As already stated, there are other molybdenum minerals that have been reported besides those described above. Definite information concerning them is, however, so meager that their existence as distinct species is problematical. Principal among these doubtful minerals are molybdurane, molybdoferrite and knightite. The first two are referred to by Moissan^b and also by Gin^c who give the formula of molybdurane as $\text{UO}_2\cdot\text{UO}_3\cdot 2\text{MoO}_4$, and of molybdoferrite as FeMoO_4 . Des Cloizeaux^d speaks of molybdurane as a molybdate of uranium, and says that it is found at Joachimsthal, Bohemia. Knightite, said to be a phosphate of molybdenum, is referred to by

^a Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district Colorado: U. S. Geol. Survey Prof. Paper 54, 1906, p. 124; also see pp. 12-13 of this report.

^b Moissan, Henri, *Traité de chimie minérale*, t. 4, 1904, p. 685.

^c Gin, Gustave, A memoir on the methods of treatment of simple and complex ores of molybdenum, tungsten, uranium, and vanadium: Trans. Am. Electrochem. Soc., vol. 12, 1907, p. 412.

^d Des Cloizeaux, Alfred, *Manuel de minéralogie*, 1862, p. 271.

Hills,^a who states that it was discovered by O. W. Knight, of Bangor, Me., in a molybdenite deposit at Catherine's Hill, of the same State.

Beside the foregoing minerals of molybdenum the presence of molybdenum in scheelite should be called to the reader's attention. Dana^b by 17 analyses of scheelite from various parts of the world shows that molybdenum is present in this mineral in quantities varying from a trace up to about 8½ per cent.

PHYSICAL PROPERTIES OF MOLYBDENUM.

Pure molybdenum is a white metal. Its appearance depends largely on the method of production. If obtained by reducing the oxides or the sulphides of molybdenum by hydrogen, it is a gray powder which under heat and pressure may be compacted into a metallic bar that is brittle and even fragile. Produced by aluminothermic methods or by reduction in the electric furnace, it is a compact metal, but owing to the absorption of carbon in the electric furnace, it is not pure and has different physical properties from the carbon-free metal, as is explained later. Pure compact molybdenum is malleable and is sufficiently soft to be filed and polished with ease. It will not scratch glass.

Within the last decade molybdenum was considered as absolutely lacking in ductility, but the research laboratory of the General Electric Co., at Schenectady, N. Y., has discovered a method of producing ductile forms of the element, which may be drawn into ribbons and fine wire.

Debray,^c one of the earlier experimenters with the metal, considered it infusible, but although he failed to melt it, he discovered that at a high temperature it absorbed carbon. Moissan^d subsequently obtained molten molybdenum in an electric furnace. Its exact melting point is still a matter of some question. The Bureau of Standards^e has placed it about 2,500° C., or 4,500° F. This is over 1,400° C. above the melting point of copper, about 1,000° C. higher than that of iron, and 745° above that of platinum. Osmium, tantalum, and tungsten are the only three metals listed by the Bureau of Standards as having higher melting points. A resumé of melting-point determinations of molybdenum is given by Pirani and Meyer.^f

Moissan^g determined the specific gravity of molybdenum as 9.01,^h but recent research has shown that this value is low, and further that

^a Hills, B. W., The molybdenite deposits of Tunk Pond, Me.: Mining World, vol. 31, 1909, p. 323.

^b Dana, E. S., A system of mineralogy, 6th ed., 1911, p. 987.

^c Moissan, Henri, Traité de chimie minérale, t. 4, 1904, p. 687.

^d Moissan, Henri, loc. cit.

^e Stratton, S. W., Melting points of chemical elements: Bureau of Standards Circular 35, 1912, 2d ed., p. 2.

^f Pirani, M. V., and Meyer, A. R., Über den Schmelzpunkt des Wolframs und des Molybdäns: Ver. deut. Phys. Gesell., Jahrg. 14, 1912, pp. 426-428.

^g Moissan, Henri, loc. cit.

^h Moissan, Henri, loc. cit.

the specific gravity of the metal increases appreciably with the amount of mechanical working to which it is subjected, a phenomenon common to many other metals, such as copper, zinc, and tungsten.^a The specific gravity of ductile molybdenum before drawing was determined in the research laboratory of the General Electric Co. as 10.02, and after drawing it ranged from 10.04 for a wire 3.75 mm. in diameter to 10.32 for a wire 0.038 mm. in diameter.

The accompanying table ^b shows the tensile strength of molybdenum wire of various diameters in comparison with that of tungsten wire of the same sizes and with that of one size of hard-drawn piano wire. It will be noted that the values for molybdenum are approximately one-half those for tungsten and for the steel wire of corresponding size; likewise, that the tensile strength of both molybdenum and tungsten increases very appreciably with the fineness of the wire. In other words, the more the metals are worked the stronger they become.

Comparative tensile strength of molybdenum, tungsten, and steel wire.

Wire.	Diameter in thou- sandths of an inch.	Diameter in mm.	Pounds per square inch.	Kilograms per square mm.
Molybdenum.....	5.0	.125	200,000 to 260,000	140 to 182
	2.8	.070	230,000 to 270,000	161 to 189
	1.5	.038	270,000 to 310,000	189 to 217
Tungsten.....	5.0	.125	460,000 to 490,000	322 to 343
	2.8	.070	480,000 to 530,000	336 to 371
Hard-drawn piano wire.....	1.5	.038	550,000 to 600,000	385 to 420
	3.0	.075	507,000	356

The electrical resistance of ductile molybdenum is 5.6 microhms per cubic centimeter for hard-drawn wire and 4.8 for annealed wire, the resistivity being measured at 25° C.^c The temperature coefficient of electrical resistance between 0° and 170° C. is 0.0050.^d

The specific heat of molybdenum as determined by Defacqz and Guichard^e is 0.072 at 93° C., 0.074 at 281° C., and 0.072 at 440° C.

The emissivity of molybdenum measured with red light having a wave length 0.650 μ has been determined by Burgess and Waltenberg^f at temperatures of 2,000° and 2,500° C. as 0.43 and 0.40, by Coblenz^g at room temperature as 0.51, and by Mendenhall and

^a Fink, C. G., Ductile tungsten and molybdenum: Trans. Am. Electrochem. Soc., vol. 17, 1910, pp. 229-233.

^b From Fink, C. G., loc. cit.

^c Fink, C. G., loc. cit.

^d Fink, C. G., loc. cit.

^e Defacqz, E., and Guichard, M., Sur la détermination de la chaleur spécifique du tungstène et du molybdène: Anal. chim. Phys., ser. 7, t. 24, 1901, p. 139.

^f Burgess, G. K., and Waltenberg, R. G., The emissivity of metals and oxides: Bureau of Standards Scientific Paper 242, 1914-15, p. 597.

^g Coblenz, W. W., The reflecting power of various metals: Bureau of Standards Scientific Paper 152, 1911, p. 197.

Forsythe^a at 1,000° and 2,400° C. as 0.44 and 0.37. Hasselberg^b has determined the numerous lines of the spectrum of molybdenum.

As already stated, molybdenum produced by the reduction of molybdic oxide with carbon in an electric furnace does not possess the same physical properties as pure molybdenum, owing to its absorption of carbon. Metal obtained by this method is gray and brittle. It is also very hard and scratches steel and quartz; even the hardest file will not cut it when it contains a certain proportion of carbon. The melting point of the gray metal is much below that of pure molybdenum, and its specific gravity is also lower, ranging from 8.6 to 8.9, depending on the amount of carbon present. When pure molybdenum is surrounded with carbon and heated to about 1,500° C., it absorbs carbon and becomes hard. Inversely, if carbon-bearing molybdenum is melted with molybdenum dioxide, the carbon in the metal is oxidized and the molybdenum is refined and takes on the physical properties of the pure metal.^c

CHEMICAL PROPERTIES OF MOLYBDENUM.

Metallic molybdenum is only slowly oxidized at ordinary temperatures, and drawn molybdenum wire retains its luster almost indefinitely. On prolonged heating at a dull-red heat it becomes covered with a white coating of molybdic trioxide, and at 600° C. it oxidizes rapidly and the trioxide formed sublimes.

Fluorine attacks molybdenum at ordinary temperatures, chlorine at a dull-red heat, and bromine at a cherry red, and iodine does not attack it appreciably at temperatures as high as 700° to 800° C. Molybdenum is readily attacked by nitric acid but is not affected by hydrochloric acid, and sulphuric acid attacks it only when hot and concentrated. Fused alkalies act only slowly on the metal, but fused oxidizing salts, such as potassium nitrate, sodium peroxide, and potassium chlorate, attack it rapidly.

Molybdenum combines with oxygen to form several oxides, the three most stable of which are the sesquioxide (Mo_2O_3), the dioxide (MoO_2), and the trioxide (MoO_3). The first two of these are basic, and few of their salts have been studied. The trioxide is acid. It is yellow when hot and white when cold. It is precipitated from solutions in hydrated form by nitric and hydrochloric acids, but is soluble in dilute sulphuric acid and the alkalies. When the hydrated oxide is gently ignited, it becomes dehydrated and much more difficultly soluble in dilute acids. When the trioxide is heated, it sublimes, sublimation commencing at 400° to 450° C.

^a Mendenhall, C. E., and Forsythe, W. E., The relation between blackbody and true temperatures for tungsten, tantalum, molybdenum, and carbon, and the temperature variation of their reflective power: *Astrophys. Jour.*, vol. 37, 1913, pp. 380-390.

^b Hasselberg, B., Die Spectra der Metalle im electrischen Flammenbogen: Spectrum des Molybdans: *K. Svenska vet. Acad. Handb.*, Ny Föl., Bd. 36, No. 2, 1902, p. 1.

^c Moissan, Henri, *Traité de chimie minérale*, t. 4, 1904, p. 689.

A large number of elements combine with molybdic oxide to form molybdates. Of these, sodium molybdate, Na_2MoO_4 , potassium molybdate, K_2MoO_4 , and ammonium molybdate, $(\text{NH}_4)_2\text{MoO}_4$, are the chief soluble salts of molybdenum. The first two of these are formed by fusion of the trioxide with the requisite amount of sodium potassium carbonate. The latter is formed by the action of concentrated ammonia on the trioxide. The heavy metals, such as barium, calcium, and lead, form molybdates which are insoluble, and use of this fact is made in analytical work. Besides the normal molybdates of the form $\text{X}'_2\text{MoO}_4$ many complex molybdates such as phospho-molybdates exist.

With the halogens molybdenum forms several compounds which vary greatly in stability. One compound, $\text{MoO}_3 \cdot 2\text{HCl}$, is of importance as it is volatile at 250° C . and its formation affords a means of separating molybdenum from tungsten.

Molybdenum forms two principal sulphides, MoS_2 and MoS_3 , both insoluble in dilute sulphuric and hydrochloric acids. These sulphides dissolve in the alkalies to form thiomolybdates of the order $\text{X}'_2\text{MoS}_4$, which react with acids to form sulphur, hydrogen sulphide, molybdenum disulphide, and molybdenum trisulphide.

Molybdenum combines with nitrogen, phosphorus, boron, carbon, and silicon. More complete references on the chemical properties of molybdenum are given by Roscoe and Schorlemmer,^a who have been quoted freely in the foregoing discussion. Moissan^b also gives detailed data on the chemistry of molybdenum.

USES OF MOLYBDENUM.

The principal use of molybdenum is in the manufacture of alloy steels to which, particularly in conjunction with chromium, manganese, nickel, cobalt, tungsten, and vanadium, it imparts many desirable properties. These steels are used for a large variety of purposes such as for crank-shaft and propeller-shaft forgings, high-pressure boiler plate, guns of large bore, rifle barrels, armor plate, armor-piercing projectiles, permanent magnets, wire, and for self-hardening and high-speed machine tools. Metallic molybdenum is used in various electrical contact making and breaking devices in X-ray tubes, and in voltage rectifiers, and in the form of wire for filament supports in incandescent electric lamps, and for winding electric resistance furnaces, and in dentistry. Molybdenum is also employed in the manufacture of chemical reagents, dyes, glazes, disinfectants, etc.

^a Roscoe, H. E., and Schorlemmer, C., A treatise on chemistry, vol. 2, 1913, pp. 1053-1082.

^b Moissan, Henri, Traité de chimie minérale, t. 4, 1904, pp. 685-758.

MOLYBDENUM STEELS.

The early experimenters with the use of molybdenum in steel were almost unanimous in condemning the metal. Thomas Blair, of Sheffield, England, in a pamphlet published in 1894,^a quotes a case "where 1 per cent of molybdenum rendered good iron red-short, and utterly worthless." The poor results obtained by most of the pioneer investigators were due to two main causes—first, the molybdenum powder or ferromolybdenum used in making the steels was generally highly impure, containing sufficient amounts of sulphur, oxides, and other deleterious substances to spoil any steel. Second, the few molybdenum steels that were prepared in such a manner as to be free from objectionable impurities were generally ruined by improper heat treatment. It is, therefore, not surprising that at the outset the element received a "black eye," and this bad reputation has been an important factor in delaying a more general recognition of the value of molybdenum in the manufacture of special steels.

Thomas Swinden was probably the first to conduct a thorough investigation of a series of strictly comparable carbon-molybdenum steels ranging in composition up to 8 per cent molybdenum and 1.2 per cent carbon. Besides proving the extreme susceptibility of these steels to heat treatment and that they were easily ruined by even a short heating at 950° C. followed by a prolonged cooling, he showed that the molybdenum increased the tendency of the steel to harden on cold working, and that the effects of oil quenching, followed by tempering, were increased by its presence. Further, his investigation demonstrated that the effect produced by molybdenum depended to a large degree upon the treatment of the steels. With normalized steels, molybdenum considerably increased the tensile strength with only a slight reduction of ductility, and this influence was most marked in high-carbon steels. Hardened and tempered steels containing 1 to 2 per cent of molybdenum showed extremely high tenacity values, accompanied by high ductility, but when steels with higher percentages of molybdenum were hardened and tempered, they actually became inferior. Annealed steels diminished in strength and ductility as the molybdenum content increased, and this diminution was noticeable when 0.9 per cent or more of carbon was present. Throughout Swinden's tests the influence of carbon in the presence of molybdenum was marked, and there is no doubt that, like tungsten, molybdenum assists in producing hardness by helping to retain the carbon in solid solution. The results of Swinden's work appear in two excellent papers.^b It suffices here to say that in a general

^a Tungsten and chromium alloys.

^b Swinden, T., Carbon molybdenum steels: Carnegie Scholarship Memoirs, Iron and Steel Inst. (London) vol. 3, 1911, pp. 66-124; and A study of the constitution of carbon-molybdenum steels, *ibid.*, vol. 5, 1913, pp. 100-168.

way molybdenum acts similarly to tungsten in steel, but that it is much more active—that is, less of it need be used to produce a given result, as might be suspected from its lower atomic weight (96) as compared with that of tungsten (184). It is impossible to give any absolute figures as to the relative influence of the two elements, as their effects are not exactly similar. Guillet^a suggested that the effective ratio of molybdenum to tungsten was 1 to 4, but this is probably too high. Giesen^b gives the ratio as 1 to 2.225, and from the tests correlated by Swinden it is seemingly between 1 to 2 and 1 to 3.

MANUFACTURE OF MOLYBDENUM STEELS.

The crucible process is generally used in the manufacture of molybdenum steel, and the molybdenum is added in the form of molybdenum powder, ferromolybdenum, or other molybdenum alloys. Molybdenum steel can, however, be made in the electric furnace, and also by the open-hearth process. It has also been produced on an experimental scale in the electric furnace directly from a mixture of hematite and molybdenite with coke, lime, and fluorspar.^c

In adding molybdenum to steel it is generally advantageous to use ferromolybdenum, ordinarily containing about 80 per cent Mo, as the melting point of this alloy is several hundred degrees centigrade lower than that of the ordinary commercial brands of powdered molybdenum. Further, powdered molybdenum seemingly is more prone to oxidation than the ferro-alloy, but on the other hand it generally contains 4 or 5 per cent of various oxides of molybdenum which may aid in removing excess carbon.

As molybdenum is generally used in steel in conjunction with chromium, tungsten, nickel, vanadium, etc., it is often added in the form of alloys with these metals. Standard alloys of this type on the market are chrome-molybdenum, with 50 per cent molybdenum and 50 per cent chromium; molybdenum-nickel, with 75 per cent molybdenum and 25 per cent nickel; and ferromolybdenum-tungsten, containing molybdenum and tungsten in the proportion of 3 to 1. From 1 to 7 per cent vanadium, according to specifications, is sometimes added to the last-mentioned alloy.

USE OF MOLYBDENUM IN TOOL STEELS.

Molybdenum acts similarly to tungsten in the presence of chromium and manganese, and in combination with either of these elements and carbon it produces a self-hardening steel which is said to be a

^a Guillet, Leon, *Revue de Métallurgie*, 1904, p. 390.

^b Giesen, Walter, *The special steels in theory and practice: Carnegie Scholarship Memoirs, Iron and Steel Inst. (London)*, vol. 1, 1909, p. 31.

^c Keeney, R. M., *The production of steels and ferroalloys directly from ore in the electric furnace: Carnegie Scholarship Memoirs, Iron and Steel Inst. (London)*, vol. 4, 1912, pp. 108-184. Describes production of molybdenum steel (pp. 173-175).

little tougher than the corresponding tungsten steel. A typical steel of this kind is one containing 4 to 6 per cent molybdenum, 1 to 2 per cent chromium, and 1.85 per cent carbon. Molybdenum likewise has the same properties as tungsten with reference to producing the high-speed qualities that enable a steel to retain its temper and hardness at a red heat. These qualities are developed by cooling the steel moderately fast from a high temperature, treatment that prevents the usual critical changes and keeps the steel in the austenitic condition. It is believed by many that high-speed steels produced with molybdenum are superior to the corresponding tungsten steels, both as regards toughness and durability. It is stated that they take a fine cutting edge. According to Gledhill,^a one of the qualities of molybdenum high-speed steel is that it does not require such a high temperature in hardening as does tungsten steel, and he states that if a temperature of 1,000° C. is exceeded, the tools made from the steels are inferior and their life shortened. Carpenter^b states, on the other hand, that molybdenum steels should be heated to 1,000° to 1,100° C. before they are cooled, whereas tungsten steel must be heated to about 1,200° C. The superior toughness of molybdenum high-speed steels is attributed to the fact that they contain more iron, as less molybdenum need be used to obtain the same result as with tungsten, and also because a lower heat is required in tempering them.

Certain difficulties, however, have been encountered in the use of molybdenum tool steels. Some users say that they are liable to crack in quenching, and others that they do not hold their cutting edge after retreatment as well as before. This deterioration in the steel upon repeated heating for dressing and treatment has been ascribed to the disappearance of molybdenum from the outer skin of the steel through volatilization. In a few instances service tests with these steels have shown irregular cutting speeds and have indicated a tendency of the molybdenum to render the tools brittle and weak in their bodies. Some users have found that molybdenum tool steel was apt to be seamy and to contain physical imperfections, also that it is apt to fire-crack during treatment. Molybdenum tool steels of high carbon content require great skill in their preparation owing to the difficulty of judging by color the definite temperature required for hardening. Further, great care in annealing molybdenum steel is necessary after it has been worked into bars and before it is cut into shapes for tools, and previous to hardening.

Some of the objectionable features mentioned above, and perhaps most of them, are due to the use of impure ingredients in the manufacture of the steels or to improper heat treatment, and undoubtedly

^a Gledhill, J. M., The development and use of high-speed tool steel: *Jour. Iron and Steel Inst.*, No. 11, 1904, pt. 2, pp. 127-182.

^b Carpenter, High-speed tool steels: *Jour. Iron and Steel Inst.*, No. 1, 1905, p. 460.

many of them can be overcome. However, most manufacturers, particularly in this country, have almost entirely discontinued the use of molybdenum as a major constituent in tool steel and are now using it largely in a minor capacity in conjunction with tungsten, cobalt, etc. Used in this way many of the difficulties mentioned above have been overcome, and the resulting steels have at the same time required certain superior qualities imparted by the molybdenum. A characteristic steel of this type is one with 16 to 18 per cent tungsten, 1.5 to 2 per cent molybdenum, 4 to 4.5 per cent chromium, and 0.6 per cent carbon, and it is said to be superior in cutting efficiency to the corresponding tungsten-chromium steel. It is also stated that the addition of the molybdenum in this steel results in a finer texture and lessens the chances of injuring the steel previous to hardening. The addition of molybdenum is particularly common in high-speed steels where cobalt is used in conjunction with tungsten. This type of steel contains about 16 to 18 per cent tungsten, 4 to 5.5 per cent cobalt, and 0.25 to 1.5 per cent molybdenum. Small percentages of vanadium are sometimes used in connection with molybdenum and tungsten in tool steels and are said to increase their strength and cutting efficiency. An analysis of such a steel containing both vanadium and cobalt in conjunction with tungsten, chromium, and molybdenum, and known as iridium steel, follows:

Approximate average analysis of iridium steel.^a

Constituent.	Per cent.	Constituent.	Per cent.
Cobalt.....	4.25	Manganese.....	
Tungsten.....	16.00	Silicon.....	
Chromium.....	3.55	Sulphur.....	
Vanadium.....	.67	Phosphorus.....	
Molybdenum.....	.80	Carbon.....	0.60
		Iron.....	b 74.00

It is stated that this iridium steel will do 60 per cent more work than the best tungsten steel.

The introduction of high-speed tool steels has completely revolutionized machine-shop practice. Gledhill ^c states that, as compared with cutting speeds of 30 to 50 feet per minute for ordinary crucible steel, high-speed steels are now made that will cut 500 feet per minute on steel, and drill cast iron at the rate of 25 inches per minute. Planing speeds of 15 to 25 feet per minute have been increased to 50 and 60 and even to 80 feet per minute. The high-speed twist drill has also made radical changes in practice. To-day it is customary to stack small plates and drill them instead of punching them, not only saving time, but avoiding the liability of injuring the

^a Hess, F. L., Cobalt, Mineral Resources, U. S., 1912, U. S. Geol. Survey, 1913, p. 967.

^b Approximate.

^c Gledhill, J. M., The development and use of high-speed tool steel: Jour. Iron and Steel Inst., No. 11, 1904, pp. 127-182.

metal by straining it. The plates for torpedo boats are now drilled instead of punched. It was formerly the custom to core in the holes in pipe flanges, but they are now drilled.

USE OF MOLYBDENUM IN MAGNET STEEL.

The molybdenum steels used in making permanent magnets are similar in composition to the high-speed molybdenum steels. They generally contain 2 to 3 per cent molybdenum, 0.5 to 0.7 per cent carbon, and sometimes about 0.5 per cent chromium. After hardening they retain their magnetism longer than hardened carbon steel, and are said to be superior to tungsten magnet steels. Some steels of this type contain up to 6 per cent molybdenum.

USE OF MOLYBDENUM IN ACID-RESISTING STEELS.

Alloyed with chromium, and sometimes with chromium and tungsten, molybdenum is used in preparing acid-resisting steels. Borchers^a states that an alloy containing 2 to 5 per cent molybdenum, about 10 per cent chromium, and a little or no carbon, is practically acid proof. Molybdenum-tungsten-chromium-iron alloys have also been made that are insoluble in hydrochloric, sulphuric, or nitric acid, and an alloy containing 60 per cent chromium, 35 per cent iron, and 2 to 3 per cent molybdenum is said to resist even the action of boiling aqua regia.^b Differences in the heat treatment of these alloys have a great effect on their acid-resisting qualities.

USE OF MOLYBDENUM IN OTHER ALLOY STEELS.

Molybdenum is used in conjunction with chromium and nickel to produce steels with a wider heat-treatment range and with even greater tensile strength than are possessed by chrome-nickel steel. These chrome-nickel-molybdenum steels contain about 1 per cent chromium, 2 to 3 per cent nickel, and 0.25 to 0.5 per cent molybdenum, and on account of their high tensile strength and elastic limit, they have a range of usefulness that is limited only by their cost. These properties make them of special value for crank shafts, propeller shafts, and other machine parts that are subjected to alternating and repeated stresses. For example, they are used to some extent in the frames and axles of automobiles and railroad rolling stock. The high tensile strength of these steels is also responsible for their use in the best grades of high-pressure boiler plate such as is used on torpedo boats. They are also employed in making guns of large bore, and rifle barrels, and for such use they have the added advantage of being highly resistant to the erosive action of the gases generated by the explosives.

^a Borchers, W., Acid-resisting alloys; *Engineer* (London), vol. 114, July 26, 1912, p. 83.

^b Benner, R. C., Recent advances in industrial chemistry: *Min. and Sci. Press*, vol. 105, 1912, p. 629.

It has been found that the addition of a small percentage of molybdenum is advantageous in the manufacture of armor plate and shields for small guns. The molybdenum is said to make the steel softer when it is annealed so that it can be planed more readily, and upon hardening, the molybdenum content produces an increased tensile strength. The exact compositions of the various molybdenum steels used in armor plate are, of course, carefully guarded secrets. Stoughton^a states that Krupp armor plate (probably of early manufacture) contains about 3.25 per cent nickel, 1.5 per cent chromium, and 0.25 per cent carbon. The assumption is safe that the introduction of 0.25 to 0.5 per cent of molybdenum in a steel of this composition would increase both its hardness and its tensile strength.

The use of molybdenum in connection with chromium is reported for producing steels of great hardness and high elastic limit, which are employed in the manufacture of armor-piercing projectiles. About 1 per cent of molybdenum added to a nickel steel is said to impart to it remarkable drawing qualities.

FERROMOLYBDENUM.

Ferromolybdenum has been used for electrodes in arc lamps.^b

USE OF MOLYBDENUM IN STELLITE.

Small percentages of molybdenum are used in certain patented non-ferrous alloys consisting essentially of chromium and cobalt. These alloys are known under the trade name of "Stellite," and possess remarkable high-speed qualities when used for machine tools. They are also employed for cold chisels, wood-working tools, cutlery, etc. Their use in cutlery is of particular interest as they do not tarnish under atmospheric influences and are unaffected by fruit acids.

In so far as molybdenum is concerned, two stellite alloys are of interest, namely, those containing cobalt, chromium, and molybdenum, and those containing cobalt, chromium, tungsten, and molybdenum. Haynes,^c the inventor of these alloys, says:

When molybdenum is added to a 15 per cent cobalt-chromium alloy [15 per cent chromium], the alloy rapidly hardens as the molybdenum content increases, until the content of the latter metal reaches 40 per cent, when the alloy becomes exceedingly hard and brittle. It cuts keenly and deeply into glass, and scratches quartz crystal with ease. It takes a beautiful polish, which it retains under all conditions, and on account of its extreme hardness its surface is not readily scratched. When 25 per cent of molybdenum is added to a 15 per cent chromium alloy, a fine-grained metal results, which scratches glass somewhat readily, and takes a strong, keen edge. Its color and luster are magnificent, and it will doubtless find a wide application for fine, hard cutlery. It can not be forged, but casts readily, and its melting point is not abnormally high.

^a Stoughton, Bradley, *The metallurgy of iron and steel*, 1908, p. 407.

^b Editorial, *Molybdenite: Min. and Sci. Press*, vol. 104, 1912, p. 781.

^c Haynes, Elwood, *Alloys of cobalt with chromium and other metals?* *Trans. Am. Inst. Min. Eng.*, vol. 44, 1912, pp. 576-577.

These stellite alloys are silvery-white. They are insoluble in nitric acid and are only slowly attacked by hydrochloric acid. Following is the analysis of a typical molybdenum stellite.

Analysis of a typical molybdenum stellite.^a

Constituent.	Per cent.
Mo.....	22.50
Co.....	59.50
Cr.....	10.77
Fe.....	3.11
Mn.....	2.04
C.....	.87
Si.....	.77
S.....	.084
P.....	.040
W.....	.00
Ni.....	.00
	99.684

USES OF METALLIC MOLYBDENUM.

The uses of metallic molybdenum have been greatly extended by the discovery of certain processes by which it can be obtained in ductile form.^b As wire, it is used for supporting the filaments in incandescent electric lamps. Of course, the quantity of the element used in a single lamp of ordinary candlepower is extremely small, but in argon-nitrogen-tungsten lamps of high candlepower the molybdenum supports are of very appreciable size and weight. Molybdenum wire is also employed for winding electric resistance furnaces, and for this use it has proved both cheaper and superior to platinum because of the quicker heating and the higher temperatures attainable.^c In this work it must, of course, be protected from the air to prevent its oxidation.

Molybdenum has been successfully substituted for platinum and for platinum iridium in various electric contact making and breaking devices. On account of its high heat conductivity in the ductile form, and because its relative cheapness permits its use in large masses, the formation of heavy coatings of nonconducting oxide are prevented, and under the conditions existing in these contacts, any thin coatings of oxide formed are conductors. The Coolidge X-ray tube and a voltage rectifier of recent manufacture have a very considerable proportion of ductile molybdenum used in their construction. Gold-covered molybdenum wire is used in dentistry to a considerable extent, and research work is being carried on to extend the use of special molybdenum alloys in this field.^d

^a Hibbard, H. D., Manufacture and uses of alloy steels: Bull. 100, Bureau of Mines, 1915, p. 61.

^b See Coolidge, W. D., U. S. Patent 1082933, Dec. 30, 1913.

^c Winne, R., and Dantsizen, C., Small electric furnace with heating element of ductile tungsten or ductile molybdenum: Jour. Ind. and Eng. Chem., vol. 3, October, 1911, p. 770.

^d Fahrenwald, F. A., A development of practical substitutes for platinum and its alloys, with special reference to alloys of tungsten and molybdenum: Am. Inst. Min. Eng., Bull. 109, January, 1916, pp. 103-149.

It is suggested that molybdenum may be successfully used with tungsten as a thermocouple for the measurement of high temperatures. The advantage in the use of these metals is that they have much higher fusing points than platinum, platinum-iridium, or platinum-rhodium couples, such as are ordinarily used, and although they oxidize at high temperatures, they might be protected from the air by covering them with fused magnesia or similar substances. The voltage curve of the molybdenum-tungsten couple has been studied by Northrup.^a

USE OF MOLYBDENUM IN CHEMICALS.

The chief use of molybdenum in chemicals is as ammonium molybdate, $(\text{NH}_4)_2\text{MoO}_4$, and sodium molybdate, Na_2MoO_4 . The first is employed principally as a reagent in the quantitative determination of phosphorus in iron and steel, various ores, fertilizers, soils, etc., and in the quantitative determination of lead. The equivalent of several tons of metallic molybdenum is said to be consumed annually in this form by the iron and steel plants in the United States for the determination of the phosphorus content of their products. It is reported that ammonium molybdate is also used for fireproofing, and as a disinfectant for cloth used in railroad coaches and for similar purposes. It is said to be a strong germicide. Sodium molybdate was at one time used rather extensively in ceramics to impart a blue color to pottery and in the manufacture of certain glazes, but it is understood to have been replaced almost wholly in this field by cobalt compounds. It is also used in dyeing silks and woolens. Molybdenum indigo, Mo_5O_7 , is used for coloring rubber and is said to be noninjurious to the material.^b

Fast colors in a large variety of shades may be produced on leather by employing molybdenum tannate in conjunction with logwood extracts.^c

A process involving the use of molybdenum for the preservation of cordite in hot climates is said to have been discovered in France.^d It is also rumored that molybdenum is used in the synthetic production of ammonia under processes covered by German patents and in which it is said to act as a "promoter" to the catalysts used. It is well known that ammonia may be made by heating molybdenum oxide or molybdenum hydroxide, or mixtures of the two, to

^a Northrup, E. F., Tungsten and molybdenum: their thermal E. M. F.: Met. and Chem. Eng., vol. 11, January, 1913, p. 45.

^b Hess, F. L., Tungsten, nickel, cobalt, etc.: Mineral Resources U. S. for 1908, U. S. Geol. Survey, 1909, p. 746.

^c Pozzi-Escot, F., Production de colours fixes sur tous genres de cuirs, par l'emploi de sels de molybdène combinés à des matières tannantes ou à des colours mordantes végétales: Compt. rend., t. 135, 1902, p. 801.

^d Editorial, Molybdenite: Min. and Sci. Press, vol. 108, 1914, p. 860.

about 500° to 600° C. with equal equal parts of nitrogen and hydrogen, and under a pressure of about 60 atmospheres, to form molybdenum nitride, which when heated in a vacuum yields ammonia and metallic molybdenum.^a

PRODUCTION OF MOLYBDENUM ORES.

Queensland, New South Wales, and Norway have to date furnished the major part of the world's production of molybdenum, the output derived from all other countries, including the United States, probably not amounting to 10 per cent of the total. Austria, Canada, France, Germany, Great Britain, Japan, Mexico, Natal, Russia, Sweden, the United States, and Australian States other than those mentioned above have at times made a small production of molybdenum ore, but with the exception of the United States their output has been too small to be worthy of consideration.

The following table shows the tonnage and value of high-grade molybdenite concentrates produced in Queensland, New South Wales, and Norway from 1902 to 1914:

Production of high-grade molybdenite concentrates in Queensland, New South Wales, and Norway, 1902 to 1914.

Year.	Queensland, ^a		New South Wales, ^b		Norway, ^c	
	Short tons.	Dollars.	Short tons.	Dollars.	Short tons.	Dollars.
1902.....	^d 45.9	^d 26,770	16.8	8,960	22	16,100
1903.....	^d 26.9	^d 10,220	32.5	21,690	34	21,400
1904.....	23.6	13,010	28.3	13,270	33	17,400
1905.....	70.8	41,340	21.7	12,200	51	16,300
1906.....	118.9	74,330	36.6	23,350	^e 1,129	11,200
1907.....	74.0	41,080	24.2	17,340	33	12,900
1908.....	98.7	44,960	9.5	4,520	39	13,400
1909.....	103.9	45,120	31.5	15,810	33	12,100
1910.....	118.6	58,640	53.2	27,580	.....	.....
1911.....	111.4	64,610	23.1	12,610	2	800
1912.....	114.6	84,420	63.3	18,030	23	5,400
1913.....	74.3	92,460	88.3	33,100	13	3,200
1914.....	87.1	185,830	68.8	55,720	.....	.....

^a Data from annual reports of the under secretary of mines, Queensland.

^b Data on quantity exported from annual report, Department of Mines, New South Wales, 1914.

^c Data from Norges Bergvaerkdrift, Norges Officelle Statistik.

^d The molybdenite production of Queensland in 1902 and 1903 as officially reported includes a small tonnage of bismuth and tungsten ore.

^e Probably ore.

QUEENSLAND.

The first official record of a production of molybdenite in Queensland was in 1900, when the output amounted to 12.3 short tons of high-grade material. The production gradually increased to 118.9 short tons in 1906, and it varied little from this figure until 1913, when it dropped to 74.3 tons, but rose again in 1914 to 87.1 tons. The

^a Tucker, S. A., and Moody, H. R., The production of hitherto unknown metallic borides: Jour. Chem. Soc., vol. 81, 1902, p. 16.

value of the production in the latter year, however, showed an enormous increase, owing to an advance in prices, and amounted to \$185,830, or more than twice the value of the 1913 production, which was only slightly less in tonnage. The total production to the end of 1914 was approximately 1,030 short tons, valued at about \$760,000. The bulk of this material was mined at Wolfram Camp, in the Chillagoe field, about 120 miles southwest from Cairns, in northern Queensland. The mines at Bamford, in the same field, are, however, credited with a small production. In 1914 the principal producing properties in the Wolfram Camp district were the Murphy & Geaney mine, which treated 1,233 long tons of ore, which yielded 20.2 tons of molybdenite, valued at £9,543, and 83.4 tons of bismuth-tungsten concentrates, valued at £5,558, and the Larkin & Wade mine, which made a total output of 1,254 long tons of milling ore, which yielded 9.65 tons of molybdenite and 54.55 tons of bismuth-tungsten concentrates. Other mines at Wolfram Camp which made smaller productions of molybdenite were the Gillian Lease, Tulley, Tulley Block, Hillside United, Smith United, and Mulligan & McIntyre. At Bamford the Trafalgar, Evening Star, Northern United, Morning Star, and Sunny Corner mines made a total output of 8.55 long tons of high-grade molybdenite.

The total production of the Chillagoe district in 1914 was 76.25 long tons of molybdenite. The remainder of the output came from the Star River (Ollera) district and from a newly discovered field at Glen Atherton, on Upper Tinaroo Creek, in the Gladstone district.

Detailed descriptions regarding the occurrence and production of molybdenite in Queensland are given in the annual reports of the acting undersecretary for mines and in the references following:

Literature on occurrence and production of molybdenite.

Saint-Smith, E. C., Molybdenite in the Stanthorpe-Ballandean districts, Southern Queensland: Queens. Govt. Min. Jour., vol. 15, 1914, pp. 184-189.

Cameron, W. E., Wolfram, molybdenite, and bismuth mining at Wolfram Camp, Hodgkinson goldfield: Queens. Govt. Min. Jour., vol. 4, 1903, pp. 350-352.

Cameron, W. E., Wolfram and molybdenite mining: Queens. Govt. Min. Jour., vol. 5, 1904, pp. 62-65.

Ball, L. C., The wolfram, molybdenite, and bismuth mines of Bamford: Geol. Surv. Pub. 248, Mines Dept., Queensland.

Ball, L. C., Rare-metal mining in Queensland—résumé of recent field studies: Queens. Govt. Min. Jour., vol. 14, pp. 4-7.

NEW SOUTH WALES.

The production of molybdenite in New South Wales was first reported in 1902. In that year the output was 16.8 short tons, valued at \$8,960. The total production to the end of 1914 was 498 short tons, valued at over \$264,000.

The principal producing molybdenite mines are at Whipstick in the Pambula division, at Kingsgate in the Glenn Innes division, and near Deepwater in the Deepwater division. The annual report of the Department of Mines for the year 1914 states that at Whipstick the Whipstick Mines (Ltd.) raised 63 long tons of ore, estimated to contain 9 tons of concentrates, valued at £5,000. At Kingsgate, in the Glenn Innes division, the Yates mine produced 8.75 tons of concentrates, containing 94 per cent molybdenite and valued at £4,700, and the Glenn Innes Molybdenite and Bismuth Syndicate sold 1.6 long tons of concentrates containing 92 per cent molybdenite for £655. The Sacks mine at Kingsgate produced 0.85 ton of molybdenite, valued at £340. In the Deepwater division the Bow Creek Molybdenite Mines (Ltd.) produced 65 long tons of ore, which yielded 1.63 tons of concentrates, valued at £735. In the same division 11 tons of ore, which yielded 1.5 tons of molybdenite concentrates, valued at £700, was mined by E. A. Baker, and 28 tons of ore, which yielded 1.4 tons of molybdenite, assaying 93 per cent MoS₂, and valued at £667, was mined at Four Mile by E. L. Key. At Rocky River, in the Tantafield division, 80 tons of molybdenite ore, valued at £631, was mined, and in the Bathurst division, 38 tons, valued at £800. The table on page 29 shows that the greatest production of molybdenite in New South Wales was in 1913, when 88 short tons, valued at \$33,100, was mined, and that in 1914 the output decreased to 68.8 tons. On account of the marked advance in prices, however, the value of the output in the latter year was more than \$20,000 in excess of the value of the production in 1913.

Detailed descriptions of the occurrence and production of molybdenite in New South Wales are given in the annual reports of the department of mines, New South Wales, and by Andrews.^a

NORWAY.

In Norway the production of high-grade molybdenite concentrates has averaged about 30 tons per annum since 1902. The table on page 29, in which the output of this country is given by years, shows that in 1906 a production of 1,129 short tons was reported. This figure doubtless does not represent the output of a high-grade molybdenite concentrate, but rather the production of ore in that year.

The principal molybdenite-producing sections in Norway are the Provinces of Lister og Mandal and Nedenes, on the extreme southern end of the peninsula. The district of Fjotland, in the former Province, is probably richer in molybdenite than any yet discovered in Norway. A mine at Knaben, in this district, has been the largest

^a Andrews, E. C., Molybdenum: New South Wales Dept. of Mines and Agriculture, Geol. Survey Min. Resources, No. 11, 1906, 17 p.

and probably the only successful producer in Norway. This mine, owned by George G. Blackwell & Sons Co., of Liverpool, England, has made an average output of about 25 short tons per annum. In 1912 about 200 tons of low-grade molybdenite ore was mined at Reinshommen, in Fjotland, and about 610 tons of ore averaging about 2.4 per cent MoS₂ at Langvand. Of this latter amount 390.5 tons was milled, yielding 0.5 metric ton of concentrates, assaying 51 per cent of MoS₂, and 10 tons of second concentrates running about 23 per cent MoS₂.^a

It is reported that on account of the increased demand and high prices being paid for molybdenum a considerable interest is being taken at the present time in developing some of the numerous Norwegian deposits. The Ore Concentration Co. (Ltd.), of London, has recently tested several parcels of Norwegian molybdenite ore aggregating over 100 tons. This company states that the Elmore oil-flotation process is in use at two mines in Norway, and that large quantities of molybdenite concentrates have already been shipped.^b

UNITED STATES.

The principal production of molybdenum ore in the United States was in 1903, when, according to Pratt,^c 795 short tons of wulfenite and molybdenite concentrates, valued at \$60,865, was marketed. Probably 750 tons, or more, of this material consisted of wulfenite concentrates obtained by sluicing tailings from a cyanide mill at Mammoth, Ariz. The ore from which these tailings were derived came from the Mammoth mine at Schultz, about 3 miles away. The remainder of the output, consisting of molybdenite concentrates, was probably derived from the Crown Point mine, Chelan County, Wash., with perhaps a ton or two from the mine of the American Molybdenum Co., at Cooper, Me., and from other sources. Previous to 1903 practically the entire commercial output of molybdenum ore in this country consisted of 20 to 30 tons of high-grade molybdenite obtained from the Crown Point mine.^d From 1903 to 1914 the United States Geological Survey has recorded a production of a marketable molybdenum product in only three years, namely, 1905, 1906, and 1907. The output in these three years was confined to small lots of molybdenite derived largely from the Crown Point mine and from a deposit near Homestake, Mont., and to a few tons of wulfenite concentrates

^a Editorial, Norwegian molybdenite: Eng. and Min. Jour., vol. 98, 1914, p. 820.

^b Editorial, Molybdenum recovery by the Elmore process: Eng. and Min. Jour., vol. 99, 1915, p. 907.

^c Pratt, J. H., The steel-hardening metals: Mineral Resources U. S. for 1903, U. S. Geol. Survey, 1904, p. 308.

^d Pratt, J. H., Tungsten, molybdenum, uranium, and vanadium: Mineral Resources U. S. for 1901, p. 268, and for 1902, p. 287, U. S. Geol. Survey, 1902 and 1903.

from Arizona.^a Official statistics as to the production in 1914 are as yet not available, but it is known to have been small and to have consisted for the most part of wulfenite concentrates obtained from a small mill erected by F. H. Hereford and R. O. Boykin, of Tucson, Ariz., to re-treat the tailings piles already mentioned at Mammoth, Ariz. Small lots of high-grade molybdenite coming from the Crown Point mine, Chelan County, Wash., and the Romero Mining Co.'s property near Porvenir, N. Mex., were also marketed in 1914.

Since January, 1915, the production of both molybdenite and wulfenite in this country has shown a notable increase. In October, 1914, the Primos Chemical Co., of Primos, Pa., purchased a molybdenite prospect on Red Mountain, near Empire, Colo., and developed the property to such an extent that shipments of ore were made in January, 1915, and it is understood that they continued at the rate of two to three 25-ton carloads per week until the mine was shut down for the winter. It is reported that the ore shipped contained 2 to 3 per cent of molybdenite. Since the beginning of 1915 an assaying and ore-testing firm of Denver, Colo., has purchased considerable quantities of molybdenite ore coming from various mines in this country and Canada, and is said to have marketed a small tonnage of molybdenite concentrates of good grade derived from these ores. The embargo placed by Great Britain on the exportation of molybdenum ore from her colonies has of course since prevented further receipt of Canadian ores by this company. It is reported that a contract was placed with another company of Denver, Colo., in 1915, for the concentration of 500 tons of low-grade molybdenite ore from a deposit on Bartlett Mountain, Summit County, Colo., and, further, that several hundred tons of low-grade ore from neighboring claims were concentrated by flotation with fair results at Leadville, Colo. Considerable development work was done on these deposits during the year. Noteworthy development, resulting in the production of a considerable tonnage of low-grade ore, was likewise done by the Leviathan Mines Co. on its molybdenite property near Copperville, Mohave County, Ariz. Several molybdenite prospects throughout the West produced small quantities of ore, and small lots of high-grade molybdenite were obtained from some of them by careful selective mining on streaks of high-grade material and by hand picking.

The production of wulfenite also increased. F. H. Hereford and R. O. Boykin enlarged their mill at Mammoth, Ariz., to over twice

^a Pratt, J. H., Steel and iron hardening metals: Mineral Resources U. S. for 1905, U. S. Geol. Survey, 1906, p. 412. Hess, F. L., Nickel, cobalt, vanadium, etc.: Mineral Resources U. S. for 1906, U. S. Geol. Survey, 1907, p. 539. Hess, F. L., Tungsten, nickel, cobalt, etc.: Mineral Resources U. S. for 1907, U. S. Geol. Survey, 1908, p. 721.

its previous capacity, and during the summer were producing a wulfenite concentrate containing approximately 22 per cent MoO_3 at the rate of about 2 tons per day.

A small production of wulfenite concentrates were said to have been derived in 1915 by Mr. Frank Widener, of Cutter, N. Mex., from a deposit about 30 miles west of that place. Considerable development work was done on the Old Yuma mine near Tucson, Ariz., and a small mill was erected for the treatment of the wulfenite ore by Col. Epes Randolph and associates of Tucson.

The author believes that the output of molybdenum contained in the molybdenite and wulfenite ores mined in the United States in 1915 will compare favorably with that of any other country. Whether it will continue to increase in the future depends entirely on the demand.

CANADA.

The production of molybdenum ore in Canada has to date been confined to small lots of high-grade molybdenite obtained by cobbing and hand-picking ore from rich streaks in certain deposits in the Provinces of Ontario and British Columbia. It is reported that these lots, which have usually averaged 500 to 2,000 pounds in weight, have been largely sold to chemical manufacturers in the United States, although a few of them have been shipped to England. In addition to this output of high-grade material perhaps 100 to 200 tons of medium-grade molybdenite ore has been shipped to the United States or to England for concentration. Of course, since the embargo placed by Great Britain on the exportation of molybdenum ore from her colonies such shipments to the United States have ceased. Although up to the present time no production worthy of mention has been made in Canada, that country has several promising deposits of high-grade molybdenite ore and is doubtless capable of a considerable production.

IMPORTS OF MOLYBDENUM.

Under the tariff of 1909 the duty on molybdenum or ferromolybdenum valued at \$200 per ton or less was 25 per cent ad valorem, and on material valued at more than \$200 per ton it was 20 per cent ad valorem. Under the existing tariff this duty was reduced to 15 per cent ad valorem, irrespective of value. Ores of molybdenum may be imported free. Although it is known that small lots of high-grade molybdenite have been brought into this country at frequent intervals, no figures as to the quantity so imported can be given, as no separate account of the imports of molybdenum ore are kept by the customs service. However, the total quantity is probably not large, as practically the entire output of Queensland, New

South Wales, and Norway which have been the principal producing countries to date, has been taken by Germany, England, and France. It is understood that during the early part of 1915 about 60 tons of high-grade molybdenite ore was imported from Canada for concentration in this country; but the action of the British Government in placing molybdenum ores, metallic molybdenum, and ferromolybdenum on the list of absolute contraband has made impossible further shipments of such material into this country, either from Canada or other British possessions.

The table following shows the amount and value of the molybdenum and ferromolybdenum imported into the United States during the years 1911 to 1915. Previous to 1911 imports of these metals were not separately reported by the customs authorities. It will be noted that during the period covered by the table imports of these metals were practically negligible.

Quantity and value of imports of molybdenum and ferromolybdenum into the United States, 1911 to 1915.

Calendar year.	Tons.	Dollars.
1911.....	8.5	11,409
1912.....	4.0	4,670
1913.....	7.0	15,939
1914.....	.1	59
1915.....	2.0	2,370

MARKET FOR MOLYBDENUM.

Under normal conditions practically 90 per cent of the world's molybdenum production is used in making alloy steel and only about 10 per cent in the manufacture of chemicals and for all other purposes. At first glance it is therefore somewhat surprising that with the greatly increased demand for alloy steels occasioned by the European war the market for the element should not have developed to a larger degree, and in a greater measure kept pace with the phenomenal demand for its sister metal, tungsten, especially as molybdenum has in the past been used principally in the manufacture of field artillery, coast-defense and naval guns, rifle barrels, armor plate, armor-piercing projectiles, etc., and of high-speed tool steel, which is finding such a large use in the manufacture of these and other munitions. The ultimate market for molybdenum has, however, always been largely in Europe, the use of the element in steel being much more popular abroad than in the United States. Up to the present time France, England, and Germany have taken practically the entire molybdenum output of the world, and in comparison an almost negligible quantity of molybdenite and wulfenite, derived from the small domestic production and small quantities of molybdenite imported, have been treated in this country. Outside

of a few companies that are purchasing high-grade molybdenite concentrates for the manufacture of chemicals, there are even to-day only five concerns in the United States that are making metallic molybdenum or ferromolybdenum. Of course, there are many ore buyers in this country who are in the market for molybdenite concentrates, but their market is in turn almost wholly abroad, and they act either as middlemen, on their own behalf, or as agents for European purchasers.

The development of the molybdenum market has in the past and is at present being retarded by the fact that manufacturers who might use or might investigate the possibilities of using the metal are kept out of the market by the fear of not being able to obtain steady supplies. On the other hand, those who might be interested in the development of some of the extensive low-grade molybdenite or wulfenite deposits in this country are prevented from doing so by the small visible demand and the fear that any large production will glut the market. Owing to these conditions, the mining of molybdenum has, as already stated, been confined in the past to small-scale operations on high-grade streaks of molybdenite ore, and the methods of recovery have been limited largely to cobbing and hand picking. The unprecedented demand for steel-hardening metals, occasioned by the European war, is, however, slowly drawing the attention of both prospective producers and consumers to the possibilities in regard to molybdenum. Several mining operations looking toward a considerable production of both molybdenite and wulfenite have already been commenced, and, on the other hand, manufacturers are investigating the possibilities of using molybdenum in a large way, and are beginning to realize that it is not as they generally supposed, due to the scarcity of the element in nature and the nonexistence of ore bodies that steady supplies have previously not been available, but rather to lack of development of these ore bodies.

How great a quantity of molybdenum the market will absorb under existing or future conditions is entirely a matter of speculation. It is the author's opinion, however, that the demand for the element will keep pace with a greatly increased production, particularly if the metal is offered at prices below those normally asked for tungsten.

HOW MOLYBDENUM CONCENTRATES ARE MARKETED.

The basis on which molybdenum ores and concentrates are bought and sold varies according to whether the contained molybdenum mineral is molybdenite or wulfenite. Molybdenite products are invariably purchased on the basis of their molybdenum content, reckoned as MoS_2 , whereas wulfenite is always bought either on the basis of its molybdenum content expressed as metallic molybdenum or as MoO_3 . It is unfortunate that custom should have established

these three methods of calculation where one, based on the content of metallic molybdenum, would have sufficed and avoided needless complications and frequent misunderstandings between buyers and sellers. In connection with the use of these three standards it may be of interest to note that 1 part by weight of MoS_2 is equivalent to 0.9 part of MoO_3 and to 0.6 part of Mo, and, inversely, that 1 part by weight of Mo is equivalent to 1.5 parts of MoO_3 and to 1.67 parts of MoS_2 .

In the United States the short ton of 2,000 pounds is the measure of weight used in buying and selling molybdenum ore, and quotations are generally based on the number of units of 20 pounds each of pure Mo, MoO_3 , or MoS_2 contained in a ton. In Europe, on the other hand, the long ton of 2,240 pounds is almost invariably used, and accordingly European purchasers settle on the basis of a unit containing 22.4 pounds. Quotations both in this country and abroad are generally made on a sliding scale to cover various grades of material. Specifications usually state the minimum percentage of Mo, MoS_2 , or MoO_3 in the ore or concentrates that is acceptable to the purchaser, and also the maximum percentage of objectionable elements, such as copper, tungsten, bismuth, arsenic, and antimony that will be allowed. Just what are objectionable elements depends largely on the use to which the molybdenum product derived from the concentrates is destined and the methods employed in treating it. Copper and tungsten seem to be universally objectionable both to the iron and steel and to the chemical trades. Copper is particularly undesirable and its presence in excess of 1 per cent, even in high-grade molybdenite concentrates, is usually sufficient to render the material unmarketable. Some dealers will, however, accept concentrates containing more than 1 per cent copper, but when 4 or 5 per cent copper is present the penalties exacted are such as to be prohibitive. Likewise, some dealers have no objection to the presence of small quantities of arsenic and bismuth in molybdenite concentrates, as they state that these elements are readily volatilized when the ore is roasted in the process of treatment. Up to 1914 it was difficult to sell molybdenite concentrates containing less than 80 per cent MoS_2 , or wulfenite concentrates with less than 25 per cent MoO_3 , but at present (March, 1916) it is reported that molybdenite and wulfenite concentrates containing as low as 20 per cent MoS_2 and 18 per cent MoO_3 , respectively, can be marketed.

PRICES OF MOLYBDENITE AND OF WULFENITE CONCENTRATES.

Under the existing abnormal conditions of the market for all steel-hardening metals it is impossible to quote exact prices for either molybdenite or wulfenite concentrates. The sale of even 1-ton or 2-ton lots is the subject of separate negotiations, and the

prices received vary between wide limits. Based on a content of 90 per cent MoS_2 , small lots of molybdenite have, during the last two years, brought in this country \$2,500 to \$3,500 per short ton, or \$27.75 to \$38.90 per 20-pound unit of MoS_2 . The price of wulfenite concentrates during the same period has ranged from \$200 to \$300 per short ton, or from \$10 to \$15 per unit of MoO_3 , based on a content of 20 per cent MoO_3 . Of course, the price paid per unit for MoS_2 or MoO_3 decreases rapidly with the grade of the material, as is well illustrated by the following schedule of prices quoted in February, 1916, by a domestic manufacturer of molybdenum and ferromolybdenum, for molybdenite concentrates. Based on a content of 50 per cent MoS_2 , the price offered was \$20 per unit of MoS_2 , with a penalty or bonus of 20 cents per unit for each per cent below or in excess of 50 per cent MoS_2 . The prices of various grades of concentrates, according to this schedule, are shown in the accompanying table:

Prices offered for molybdenite concentrates in February, 1916.

Per cent MoS_2 in concen- trates.	Price offered—	
	Per unit.	Per short ton.
30	\$16	\$480
40	18	720
50	20	1,000
60	22	1,320
70	24	1,680
80	26	2,080
90	28	2,520

As already stated in the discussion of the market for molybdenum, concentrates of both molybdenite and wulfenite must be practically free from deleterious elements, such as copper, tungsten, antimony, arsenic, and bismuth, to command the best prices, and a copper content of more than 2 or 3 per cent generally precludes their sale or else exacts heavy penalties. The following table, which was compiled mainly from quotations furnished through the courtesy of L. Lamy, of Paris, France, shows the fluctuations in the price of high-grade molybdenum concentrates (90 to 95 per cent MoS_2) in European markets since 1907. The table shows that the price has more than trebled in the past three years:

*Prices of high-grade molybdenite concentrates (90 to 95 per cent MoS_2) in European mar-
kets, 1908 to 1915.*

Year.	Prices per unit of 20 pounds.	Prices per unit of 22.4 pounds.	Year.	Prices per unit of 20 pounds.	Prices per unit of 22.4 pounds.
		<i>Shillings.</i>			<i>Shillings.</i>
1908.....	\$6.50 to \$7.60	30 to 35	1912.....	\$7.15 to \$11.95	33 to 55
1909.....	5.65 to 7.15	26 to 33	1913.....	10.90 to 18.50	50 to 85
1910.....	6.30 to 6.75	29 to 31	1914.....	19.50 to 31.50	90 to 145
1911.....	6.95 to 9.10	32 to 42	1915.....	23.90 to 36.90	110 to 170

In conclusion, it may be said that prices at present are wholly abnormal, and companies engaged in the mining or concentration of either molybdenite or wulfenite should be prepared for the sharp decline that is almost certain to follow the cessation of hostilities in Europe. Just what the normal price will be is hard to predict, as there are too many uncertain factors to be considered. As already stated, it is the opinion of the author that the demand for molybdenum will continue to increase, particularly if the price of the metal declines so that it closely approaches the normal price of tungsten. Any large production of molybdenum, such as might be derived from the several extensive deposits of low-grade molybdenite ore that are now being developed in this country, would, in all probability, not only cause such a decline in price, but might possibly enable molybdenum to be sold even below the normal price of tungsten. Although it is not safe to make any prediction as to the minimum price at which molybdenum may be marketed in the future, it may be assumed that if the chief use of the metal continues to be in the manufacture of special steels, maximum prices will never greatly exceed twice the corresponding price of tungsten, as the effective ratio of the two metals in steel is slightly above 1:2, and in many instances steel manufacturers could substitute one for the other within certain limits without materially affecting their product.

The present abnormal prices for molybdenite and wulfenite concentrates are, of course, reflected in the quotations on metallic molybdenum and ferromolybdenum. Prices in this country (March, 1916) are nominal at \$4 to \$5 per pound of metallic molybdenum, whereas in England they are slightly lower, averaging about 15s. 6d. or \$3.75 per pound. It is of interest to note that inasmuch as supplies of molybdenum and tungsten are of vital importance in the manufacture of munitions, Great Britain, acting through the governments of her various colonial possessions where ores of these metals are produced, has established a maximum price at which these ores may be sold. As regards molybdenum ore this price is 105s. per unit of MoS_2 , and for tungsten ore it is 55s. per unit of WO_3 . Taken in connection with the placing of these metals and their ores and alloys on the list of absolute contraband, this fixing of prices by the British Government has resulted in an extraordinary difference in the relative prices of the two metals in the United States and Great Britain. Quotations on ferrotungsten (75 to 85 per cent tungsten) are (March, 1916) about \$8.50 per pound of contained tungsten in this country as compared with 6s. 6d. to 7s. (\$1.58 to \$1.70) in Great Britain. In other words, molybdenum is being sold in the United States at less than half the price of tungsten, whereas in Great Britain the reverse is the case. However, this great difference in price is not to be wholly accounted for by the conditions mentioned above,

but it is partly due to the fact that the use of molybdenum is much more popular abroad than in this country. For example, some well-known European metallurgists are understood to prefer to purchase molybdenite ore at 120s. per unit of MoS_2 rather than tungsten ore at 55s. per unit of WO_3 . In this country, on the other hand, the demand for tungsten is far in excess of that for the comparatively little-known molybdenum.

QUALITATIVE TESTS FOR MOLYBDENUM.

One of the best and most easily applied qualitative tests for molybdenum is made by treating the finely powdered ore with about 5 c. c. of concentrated nitric acid, evaporating to dryness, treating the residue with $\frac{1}{2}$ c. c. of concentrated sulphuric acid and again evaporating to dryness. If molybdenum is present a beautiful ultramarine blue color develops in the residue on standing. This characteristic color generally appears in two hours or less, but sometimes 12 hours may be required, depending on the temperature and the humidity.

Another test that is highly recommended is to fuse the finely powdered ore with a mixture of sodium and potassium carbonates (1 to 1) and a small amount of potassium nitrate. The fusion is powdered and extracted with hot water and filtered, the filtrate acidified with hydrochloric acid, the carbon dioxide expelled by boiling, and potassium or ammonium thiocyanate, together with a small piece of metallic zinc, added. If molybdenum is present a bright cherry-red color rapidly develops which disappears on standing in the presence of the zinc. If hydrogen peroxide is added to the solution immediately after the cherry-red color has developed, the color disappears, returning as soon as the peroxide has been reduced. If only small proportions of molybdenum are present, it is suggested that immediately after the thiocyanate and zinc have been added to the acidified filtrate from the leached carbonate fusion, the solution be shaken with a small volume of ether. Any color in the liquid will be extracted by the ether and intensified as a golden brown in the ether ring that forms at the top of the liquid on standing, thus perhaps making visible color that before was imperceptible.

Should there be an imperfect fusion and any extraction of iron in the leach from the fused carbonates, a cherry-red color will immediately develop on the addition of the potassium or ammonium thiocyanate to the solution. With the addition of zinc, however, the color due to iron disappears, and unless a large quantity of iron has been brought into solution the color will completely disappear prior to the development of any color due to molybdenum. If this color reaction of iron and its disappearance on the addition of zinc is borne in mind, the above test for molybdenum is infallible.

Blowpipe and simple chemical tests for the various molybdenum minerals are given on pages 8 to 15.

QUANTITATIVE DETERMINATION OF MOLYBDENUM.

Previous to the quantitative determinations of the molybdenum in the ores and products obtained therefrom in the concentration tests described in this report, a brief study of published methods for determining the element was conducted by J. C. Morgan, junior chemist, in the Denver office of the Bureau of Mines, to whom the author is indebted for data in the following discussion.

It was found that most of the published methods were open to objections as hereinafter outlined. Further, several precipitation methods that would, without doubt, give correct results on practically pure salts of molybdenum were absolutely inaccurate when applied to certain ores and particularly to low-grade ores. In view of the difficulties encountered, a brief preliminary discussion of the more common methods for the quantitative determination of molybdenum may be of interest here.

SOLUTION.

The general methods of getting the molybdenum in an ore into solution are as follows: (1) By fusion with a mixture of sodium and potassium carbonates and subsequent leaching of the molybdate formed with hot water; (2) by fusion with a mixture of sodium carbonate and sulphur (1 to 1) and the leaching of the sulpho-molybdate formed with hot water; (3) by fusion with sodium peroxide or sodium hydroxide followed by leaching the molybdate formed with hot water;^a (4) by solution obtained through evaporation, first with fuming nitric acid, and then with concentrated sulphuric acid.^b

The fusion methods all have one common disadvantage for ores containing silica in excess of 10 per cent or thereabouts, in that the greater part of the silica is brought into solution and must be removed previous to the precipitation of the molybdenum. Otherwise the molybdenum precipitate is contaminated with silica. The removal of the greater part of the silica necessitates a tedious evaporation, with subsequent filtration and washing of the precipitate. Further, if the alkaline solution is evaporated as in Low's method,^c the precipitated silica is gelatinous and difficult to wash free from molybdenum salts. If the solution is acidified with hydrochloric acid, as is usual in the precipitation of silica, molybdic trioxide is precipitated on evaporation. One advantage of the fusion methods is that lead, copper, bismuth, iron, and aluminum are left in the residue from the leach, thus precluding the necessity of their removal later.

^a Darroch, James, and Meiklejohn, C. A., A rapid method of determining molybdenum: Eng. and Min. Jour., vol. 82, 1906, p. 818.

^b Colett, E., and Eckhardt, M., Bemerkungen zur Bestimmung des Molybdäns im Molybdänglanz: Chem. Ztg., Jahrg. 33, 1909, p. 968.

^c Low, A. H., Technical methods of ore analysis, 1913, p. 185.

The method of solution by digesting with fuming nitric acid followed by evaporation to dryness, fuming with a small quantity of concentrated sulphuric acid, and diluting, brings all of the molybdenum into solution, if the final residue is washed with dilute ammonia. Any silica or lead present is left in the residue. In contrast to results with fusion methods, copper, bismuth, iron, and aluminum are brought into solution. The removal of these elements, however, seems to offer less difficulty than the removal of silica in the fusion methods.

PRECIPITATION.

Many methods have been advanced for the precipitation of molybdenum from solution. The chief of these are as follows: (1) Precipitation as molybdenum trisulphide, (2) precipitation as mercurous molybdate, (3) precipitation as lead molybdate, and (4) precipitation as barium molybdate.

The complete precipitation of molybdenum as molybdenum trisulphide may be accomplished in several ways, as follows: (1) By saturating a cold solution, slightly acid with hydrochloric or sulphuric acid, with hydrogen sulphide and heating in a pressure flask;^a (2) by saturating an alkaline solution with hydrogen sulphide, acidifying with either hydrochloric or sulphuric acids, and heating in a pressure flask;^b (3) by saturating an ammonical solution with hydrogen sulphide, acidifying with hydrochloric acid, coagulating, filtering, evaporating the filtrate to dryness, expelling the greater part of the ammonium salts, extracting the residue with water containing a small amount of ammonia, adding ammonium sulphide, and acidifying with hydrochloric acid, thus removing the last traces of molybdenum;^c (4) by adding thioacetic acid and heating the precipitated molybdenum sulphide in a pressure flask.

The precipitation of mercurous, lead, or barium molybdate is accomplished by adding a solution of a salt of these metals to the molybdate solution. With sulphide ores the precipitation of either lead or barium molybdate is impracticable, as no matter what method of solution is used there is invariably enough sulphate present to cause a considerable error through the precipitation of lead or barium sulphate. The prevention of the precipitation of lead sulphate by the use of either sodium or ammonium acetate in hot solution when precipitating lead molybdate is not advisable, owing to the large quantity of acetate required.

The precipitation of mercurous molybdate is usually accomplished by adding a slightly acid mercurous nitrate solution to the solution obtained from the carbonate fusion, to which nitric acid has been

^a Treadwell, F. P., Analytical chemistry, vol. 2, 1912, pp. 285-286.

^b Treadwell, F. P., loc. cit.

^c Colett, E., and Eckhardt, M., loc. cit.

added until the solution is only slightly alkaline.^a Considerable trouble is experienced in obtaining the right degree of alkalinity. Care must be taken not to obtain an acid solution, as molybdic trioxide may precipitate.

CONVERSION OF PRECIPITATE TO WEIGHABLE FORM.

Molybdenum may be weighed as MoO_3 , MoS_2 , PbMoO_4 , or BaMoO_4 . When precipitated as MoS_3 there are two courses open—either ignition to MoO_3 or to MoS_2 in a stream of hydrogen, according to the Rose method. The fact that MoO_3 is readily volatile at temperatures higher than 400° to 450° C. necessitates great care in igniting. The complete conversion of the MoS_3 to MoO_3 requires long ignition at a temperature that should not greatly exceed 350° C. The regulation of this temperature by the ordinary Bunsen flame is extremely difficult and requires much practice. In reducing to MoS_2 many ignitions are sometimes required to obtain a constant weight.

The conversion of mercurous molybdate to molybdic trioxide by volatilizing the mercury requires extreme care and much time, and it is almost impossible to expel all the mercury without volatilizing some of the molybdic oxide. Lead and barium molybdate precipitates are weighed as such after the precipitates have been dried.

VOLUMETRIC DETERMINATION OF PRECIPITATED MOLYBDENUM TRISULPHIDE.

Several volumetric methods have been offered for the determination of molybdenum, but all require that the molybdenum first be freed from the other metals. These methods are, therefore, only of value when applied to ore analysis to determine the molybdenum from a re-solution of the final sulphide precipitate. A valuable volumetric method for such a determination is that of Randall.^b In this method a solution of the sulphide, acidified with sulphuric acid, is passed through a zinc reductor into a ferric iron solution, and the ferrous iron formed is titrated with permanganate. The advantage that volumetric methods have over gravimetric methods is that they eliminate tedious and difficult ignitions.

In general, practically all molybdenum ores carry silica, together with such metals as iron, aluminum, copper, and lead, so that the most desirable method of analysis would be one in which these elements could be eliminated most expeditiously and completely and give a final molybdenum precipitate readily convertible to a weighable form. A well-tested method that does this most efficiently is that of Colett and Eckhardt.^c

^a Low, A. H., loc. cit.

^b Randall, D. L., The behavior of molybdic acid in the zinc reductor: Am. Jour. Sci., ser. 4, vol. 24, 1907, p. 313.

^c Colett, E., and Eckhardt, M., loc. cit.

METHOD ADOPTED BY THE BUREAU OF MINES.

Inasmuch as the ores treated carried only traces of arsenic or antimony and no tungsten, no account was taken of these metals in the procedure employed. Special precautions are necessary when these metals are present in appreciable quantity. The procedure for the separation of molybdenum from these metals may be found in any of the more complete texts on molybdenum analyses.

Directions covering the method adopted by the Bureau of Mines follow:

Digest the sample of ore—from 0.2 gram to 5 grams, depending upon its seeming richness—with 25 to 35 c. c. of fuming nitric acid in an Erlenmeyer flask for three hours and finally evaporate to dryness. Add 3 c. c. of concentrated sulphuric acid to the residue and heat until dense white fumes are given off in quantity. Cool, dilute to 100 c. c., and filter. Wash the residue with water, allowing the wash water to run into the filtrate. Wash the residue well with dilute ammonia (1 to 3), and then with water. Make the filtrate alkaline with ammonia to precipitate the aluminum and any iron present in the original mineral. Heat, filter, and wash well with hot water. Saturate this alkaline filtrate with hydrogen sulphide to a bright cherry-red color. Filter and wash with hot water. Acidify the filtrate with hydrochloric acid until slightly acid and digest until the precipitated sulphide and sulphur are well coagulated and the excess hydrogen sulphide expelled. Filter on a weighed Gooch crucible. Evaporate the filtrate to dryness in a casserole and drive off the ammonium salts at the lowest possible temperature, being careful not to heat the casserole to redness at any time. Take up the final residue with about 100 c. c. of water to which 5 c. c. of ammonia has been added. Add 10 c. c. of ammonium sulphide, make faintly acid with hydrochloric acid, and digest until the sulphide is coagulated. Filter this on the Gooch crucible used for the previous sulphide filtration. Add an amount of sulphur to the combined sulphides equal to about one-half their weight and ignite over a Bunsen burner at a dull-red heat in a stream of arsenic-free hydrogen for 10 minutes. The ignition may be accomplished by using a Rose crucible cover and tube over the Gooch crucible. Weigh and repeat the ignition as before, until check weights are obtained. The weight obtained is the weight of molybdenum disulphide.

PART II. DESCRIPTION OF DEPOSITS.

GENERAL DISTRIBUTION OF DEPOSITS.

A brief field investigation confined to the examination of the better known occurrences of molybdenum in six of the Western and Pacific Coast States, namely, Arizona, California, Colorado, Montana, New Mexico, and Washington, has been sufficient to show that, contrary to general belief, there are in this country large low-grade deposits of both molybdenite and wulfenite ores from which considerable tonnages of marketable concentrates might be obtained.

Examinations of the various deposits were made solely with the purpose of determining their commercial possibilities. Most of those visited were in the prospect stage, and as many of those in the States of Colorado, Montana, and Washington were seen in the late fall when they were covered with snow, some of the following descriptions may seem to appear brief and incomplete. It is hoped, however, that the descriptions and the tabulated information regarding the known occurrences of molybdenum ores in the various States will be of value to those who are interested in deposits of this metal.

ARIZONA.

Arizona has many deposits of molybdenite and of wulfenite, and with the exception of Nevada it is the only State in which any noteworthy deposits of the latter mineral have been reported. Wulfenite ores from Arizona have supplied the larger part of the molybdenum produced in this country to 1915, and on account of the ease with which they are concentrated they should prove a strong competitor of molybdenite for markets that do not require concentrates with a high molybdenum content.

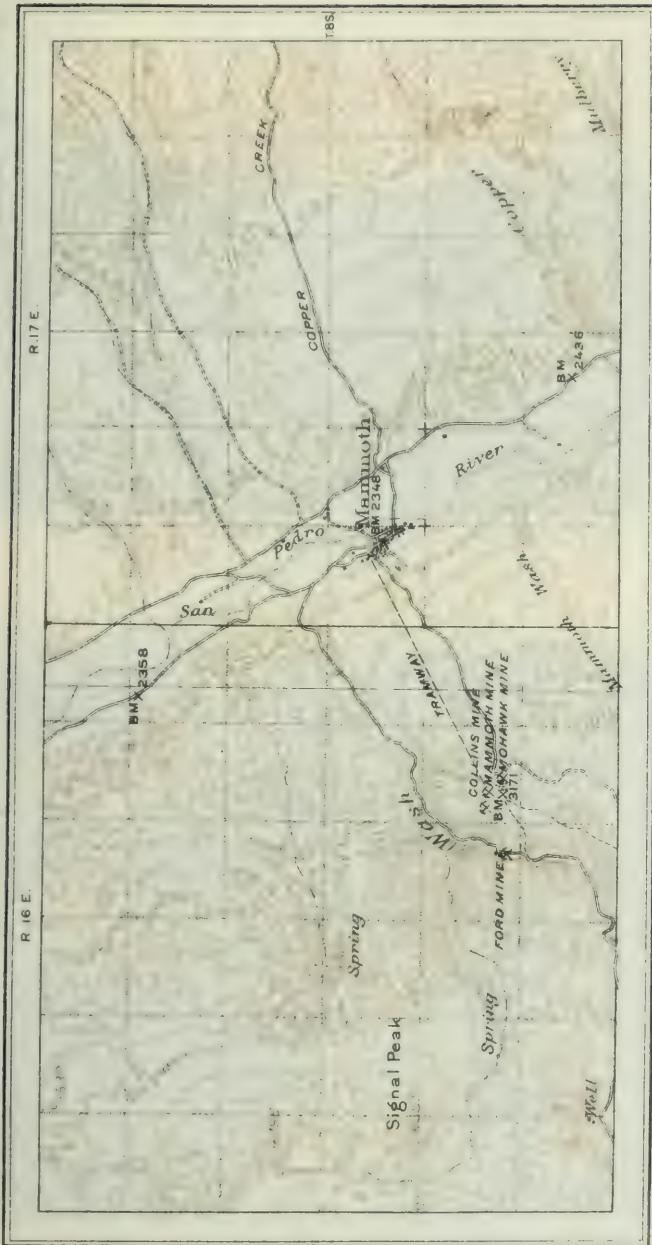
The deposits of wulfenite ore are largely confined to the four southern counties, Cochise, Pima, Pinal, and Yuma, with a few in Gila, Maricopa, and Yavapai Counties. Molybdenite has been reported from only six counties—Greenlee, Gila, Mohave, Pima, Pinal, and Santa Cruz. In most of the Arizona deposits the molybdenite is associated with chalcopyrite and other copper minerals, and inasmuch as the copper in the concentrates must be separated by further treatment the deposits are not as desirable as those free from copper. However, notwithstanding the unfortunate association of copper, some of these deposits will doubtless prove of commercial importance.

WULFENITE AT THE MAMMOTH AND COLLINS MINES, PINAL COUNTY.

The Mammoth and the Collins are adjoining mines situated at Schultz, in the Old Hat mining district, Pinal County, about 3 miles west of Mammoth and 48 miles north-northeast from Tucson, the railroad point from which supplies are brought over a good wagon road via Oracle. The mines are in section 26, T. 8 S., R. 16 E., in hilly, desert country, on the easterly slope of the drainage basin of the San Pedro River. Their location with reference to Mammoth and the main topographic features of the vicinity are shown in Plate VI. A view of the buildings and dump of the Mammoth mine is given in Plate VII, A. No wood for fuel or for mine timbers is available near by. Fuel oil and distillate for power and wood for timbering are hauled from Tucson. The elevation at the collar of the Mammoth shaft is 3,213 feet, and the collar of Collins shaft about 750 feet to the southwest is 65 feet higher.

The mines are situated on two roughly parallel veins that are about 600 to 700 feet apart. The veins strike in a general northwest to southeast direction and dip to the southwest. The dip of the Mammoth vein varies from 45° to 72° . Its average dip between the 300-foot and the 750-foot levels is $69^{\circ} 31'$, but at the 750-foot level it is only about 45° . From the surface to the 300-foot level the average dip of the Collins vein is about 72° , but grows flatter below. The veins vary greatly in width, both along the strike and the dip. The Mammoth vein is 1 or 2 inches to 60 feet wide, the part that has been explored south of the main shaft and that roughly constitutes "the south ore shoot" averaging 13 to 15 feet wide for a horizontal distance of about 750 feet. Work on the Collins vein indicates that it has an average width of 12 to 13 feet.

The filling of the Mammoth vein seems to be a mixture of brecciated rhyolite and granite, the whole so highly altered and silicified that its exact classification is impossible. The ore contains wulfenite, vanadinite, descloizite, cerussite, anglesite, chrysocolla, azurite, malachite and small quantities of gold and silver. A few pockets of galena carrying a little silver are found in some of the stopes. The filling of the vein in the Collins mine is similar to that of the Mammoth vein except that it consists almost entirely of altered rhyolite(?). The accompanying minerals in the two veins seem to be identical. The geologic history of the veins is complex and has not been thoroughly studied. Speaking in a general way, however, one may say that they were formed by intrusions of rhyolite(?) along faults in the granitic country rock, the whole being subsequently shattered by faulting and mineralized. The character of the rock of the walls is very irregular; in some places the hanging wall is rhyolite and the



MAP OF THE VICINITY OF MAMMOTH, ARIZONA,
SHOWING LOCATION OF MAMMOTH MINE

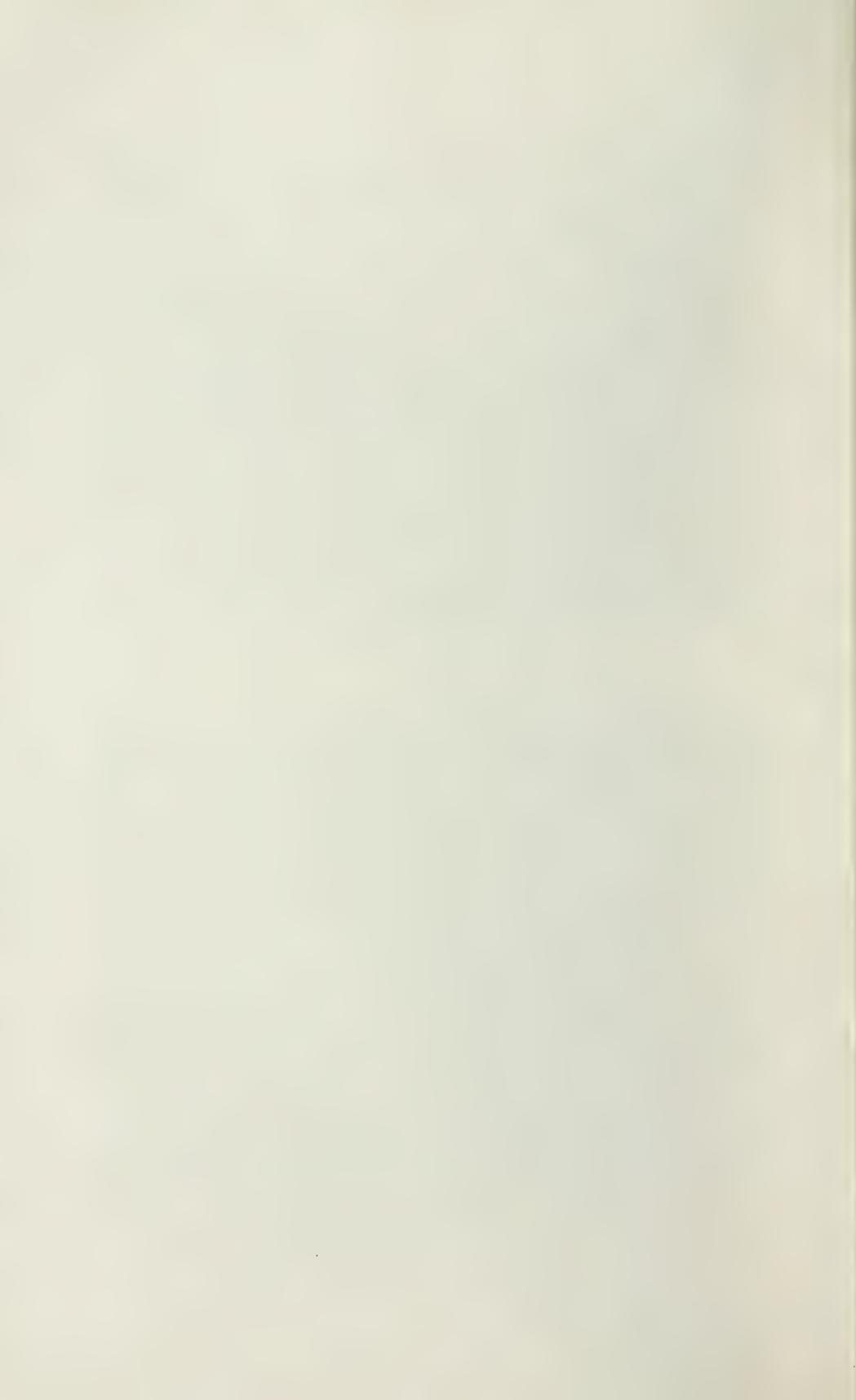
Scale 1:250,000 $\frac{1}{2}$ Miles 0 Miles $\frac{1}{4}$ Miles $\frac{1}{2}$ Miles 1 Miles 2 Miles 3 Miles 4 Miles 5 Miles 6 Miles
(contour interval 100 feet.)



A. BUILDINGS AND DUMPS OF MAMMOTH AND COLLINS MINES, SCHULTZ, ARIZ.



B. CRYSTALLIZED WULFENITE (BLACK) IN LEAD CARBONATE (WHITE) FROM MAMMOTH MINE, SCHULTZ, ARIZ. (NATURAL SIZE).



foot wall granite, and vice versa. Seemingly the zone of mineralization repeatedly crossed and recrossed the shattered rhyolite. The primary deposition of the economic minerals was probably as sulphides, and the existing minerals may be considered as almost wholly of secondary origin.

Wulfenite is of common occurrence throughout the veins and much of it is beautifully crystallized. The Mammoth mine alone has probably furnished more fine cabinet specimens of the crystallized mineral than any other locality. Most of the crystals are light orange, but they range through various shades of orange, brown, and green, to almost black. Plate III, *B*, shows a remarkably fine group of crystals from this mine. In many places there are 1-inch and 2-inch streaks of nearly pure wulfenite near the center of the ore bodies, and many cracks and fractures throughout the vein material are filled with the mineral. On the 750-foot level of the Mammoth mine the writer noted a shoot of wulfenite and cerussite ore, exposed for 100 feet or more, that averaged 10 to 12 inches wide, and probably contained 20 to 30 per cent of wulfenite. Plate VII, *B*, shows a characteristic occurrence of a veinlet of crystallized wulfenite in cerussite. In many cases the wulfenite is intimately associated with vanadinite, whereas in others the two minerals occur separately.

Veinlets and minute stringers of wulfenite are visible throughout the stopes and in the roofs and floors of most of the drifts. The writer estimates that as a whole the ore bodies contain perhaps 1 to 2 per cent of the mineral. The mines have, however, never been worked for wulfenite, but have been developed chiefly for gold, of which their ores are said to carry \$6 to \$7 per ton. Years ago, 225,000 to 250,000 tons of ore were taken from the Mammoth mine and treated by stamp milling and amalgamation at Mammoth, 3 miles away. Later the old tailing piles were treated for gold by the cyanide process, and still later parts of them were sluiced to extract the wulfenite. At present these tailings are being re-treated for the third time for their wulfenite content, as described on pages 113 to 115.

Several years ago control of both the Collins and the Mammoth mines, which had been idle for many years, was obtained by the Messrs. Young, who installed new machinery and other equipment and did considerable development work with a view of active mining.

Development on the Mammoth mine consists of a main shaft 833 feet deep and about a mile of drifts on eight different levels. The workings on the north side of the shaft have caved badly to within 125 feet of the shaft and are mostly inaccessible. On the 750-foot level it is, however, possible to go 350 feet north of the shaft, but only with great danger. The vein at this level on the north side varies from 6 to 60 feet wide. On the south side of the shaft the principal work has been done on the first, third, fourth, fifth, sixth,

and seventh levels, and aggregates perhaps 4,000 feet of drifts. Much ore has been stoped, but the ground has not caved to any extent. The water level in the Mammoth mine is about 760 feet below the collar of the shaft.

The Collins mine is opened by a tunnel 550 feet long and by a shaft down 700 feet. The principal drifts are as follows: One 325 feet long on the 100-foot level, and one 300 feet long on the 200-foot level. In all, the Collins mine has perhaps 2,000 feet of tunnel and drifts.

The Mammoth mine is equipped with a shaft house, engine and compressor house, boiler house, machine and blacksmith shops, oil storage tanks, etc. Power is generated by two Fairbanks-Morse engines which use "tops" or a No. 2 distillate costing (June, 1915) about 5 cents per gallon in Tucson. One of these engines, rated at 100 horsepower, is belted to a Sullivan angle-compound compressor capable of delivering 528 cubic feet of air per minute at 100 pounds pressure. The other engine, rated at 150 horsepower, is direct connected to a 440-volt generator which supplies power for the mine pump, electric lights, and various small motors used in the machine shop, etc. The hoisting equipment consists of a 12-inch by 14-inch double-drum hoist, which can be operated either by steam or compressed air. The mine pump is situated on the 750-foot level. It is a Prescott direct-connected motor-driven pump with a lifting capacity of 400 gallons per minute against a head of 900 feet.

Both the Mammoth and the Collins mines could, without doubt, produce a large tonnage of low-grade wulfenite ore containing perhaps 2 to 3 per cent of the mineral, and with careful selective mining could produce considerable high-grade ore. It is the writer's opinion, however, that a high-grade wulfenite concentrate could not be produced by treating the ore as a whole by ordinary wet methods on account of its containing considerable cerussite. In fact, a concentrate obtained in this way from ore of ordinary grade from the Mammoth mine showed on analysis only 14.45 per cent molybdic trioxide (corresponding to 39.4 per cent of wulfenite), but 54.54 per cent lead. The vanadinite and copper minerals present in the ore would also tend to detract from the value of the product. However, concentrates of the grade indicated above are salable, and ways might be devised for separating the bulk of the cerussite. It is reported that the wulfenite from these mines contains a small amount of gold.

WULFENITE AT THE OLD YUMA MINE, PIMA COUNTY.

The Old Yuma mine is situated about 14 miles northwest of Tucson, and 5 miles southeast of the Southern Pacific Railroad in the foothills of the Tucson mountains. To reach it one follows an excellent county road for a distance of 11 miles and then takes a poor road for about 3 miles. The mine is in desert country, and neither water nor timber

is available in the immediate neighborhood. At the mine an inclined shaft had been sunk to a depth of about 300 feet (November, 1913) on the vein, which dips about 45° southeast. Other development work consisted of about 300 to 400 feet of drifts, a few feet of raises, and a second shaft which had been abandoned but which was said to be about 100 feet deep.

The hanging wall of the vein is in many places fairly well defined, but inasmuch as the foot wall is indistinct and the crosscuts were few, the writer's estimate of 8 to 10 feet as the average width of the deposit is only approximate. The maximum width observed was about 20 feet in a crosscut on the 65-foot level. The vein material consists of what is seemingly an acid eruptive rock, badly shattered and which has been so highly altered that it is difficult to classify. It carries wulfenite, vanadinite, and cerussite, and in many places is heavily stained with iron oxides.

The wulfenite occurs in seams and cracks throughout the ore in thick, tabular crystals, which are commonly one-eighth of an inch and sometimes even an inch in maximum diameter; also as minute specks and irregular masses in the cavities of the rather porous vein material. The wulfenite crystals generally have a bright orange-yellow color, but some are greenish-black to black. Others are bicolored, having black centers and orange-yellow edges, and in some crystals one entire side may be black and the other side orange. The black coloration of these crystals is of economic interest, as it is seemingly due to the presence of finely divided metallic gold, which can be plainly seen in some crystals with the aid of a high-power microscope. The occurrence of native gold in these crystals is discussed in detail on page 115. It suffices here to say that assays made by the author of the orange-colored crystals failed to show even traces of gold, but that those of hand-picked lots of black crystals showed about 140 ounces of gold per ton.

Much of the wulfenite is associated with either cerussite or well-crystallized vanadinite or both; again, these three minerals may occur entirely distinct from one another.

The quantity of wulfenite present is greatly in excess of the vanadinite and cerussite, but no figures as to the average content of the ore in the three different minerals are available, as to the writer's knowledge the mine has never been sampled with the view of determining such data. A 120-pound lot of ore sent to the Bureau of Mines for concentration tests, which was said to be a sample across a 20-foot face on the 65-foot level of the mine, contained 6.08 per cent molybdic trioxide, which corresponds to about 15.5 per cent wulfenite. This sample was undoubtedly much richer in molybdenum than the average run of ore in the mine, which the writer would estimate as probably containing not over 2 or 3 per cent wulfenite.

It is reported that this mine was originally opened for gold, and that on an average the ore contains about one-half an ounce of this metal per ton. Owing to the distance of the property from a water supply sufficient to run a mill, the mine has never been operated to any extent, and at the time of the writer's visit the only ore that had been extracted was that encountered in development. At that time the only equipment at the property was a small dismantled hoist. No pumping had ever been necessary, and the mine was perfectly dry throughout, even at the bottom of the 300-foot shaft.

The wulfenite in the ore is readily concentrated both by wet and dry methods. If, as demonstrated by the concentration tests of the 120-pound sample of ore referred to above most of the gold is contained in the wulfenite, these concentrates should be of high value, as the molybdenum, lead, and gold contained in them can be readily separated and recovered. For a detailed description of the concentration tests made on ore from this mine, see pages 111 to 115.

The writer has been advised that in 1915 this mine was bonded to Col. Epes Randolph and associates, of Tucson, Ariz., who have erected a mill for concentrating the ore and commenced extensive development of the mine.

OTHER OCCURRENCES OF WULFENITE IN ARIZONA.

Besides the wulfenite deposits of the Mammoth, Collins, and Old Yuma mines described above there are many other promising occurrences, particularly throughout the southern part of the State. The Red Cloud, Melissa, and Hamburg mines, which are situated in the Silver mining district, Yuma County, about 80 miles up the Colorado River from Yuma, the nearest point on the railroad, are said to contain a noteworthy quantity of wulfenite in their ores, and have produced many finely crystallized specimens of the mineral. However, these mines have not been operated for many years and have never made any commercial production of wulfenite. Specimens from the Red Cloud and the Hamburg mines show that the wulfenite is often associated with vanadinite. Wulfenite is also reported as occurring at Dome, in the same county, with cerussite in a fluorite gangue, likewise in considerable quantities in several mines in the Castle Dome district, about 30 miles to the north.

In Pima County a property consisting of three and one-half claims owned by Louis Ezekiel, of Tucson, and situated about 25 miles west of that city, is said to show 2 or 3 per cent of wulfenite associated with vanadinite in a well-defined quartz vein. R. O. Boykin, of Tucson, and associates are the owners of a prospect 20 miles from that city and within one-quarter mile of a good wagon road; it is said to show 3 feet of ore carrying 3 per cent of wulfenite associated with vanadi-

nite. Concentration tests are reported to have yielded a product containing about 25 per cent molybdic trioxide. Sufficient water supplies to run a small mill the year round is said to be obtainable from a stream nearby.

According to Pratt^a there is an occurrence of wulfenite in a mine opened for copper at Troy, in the eastern part of Pinal County, within a few miles of the Gila County line. The wulfenite is said to occur in veins of quartz, which carry 1½ to 3 per cent of the mineral. Pratt further states that, "A concentrating mill has been erected for separating the wulfenite from its gangue, and the Troy-Manhattan Copper Co., which owns the property, is installing a plant for treating the wulfenite concentrates." Inquiries by the writer failed to show that this property had ever become a commercial producer of wulfenite.

J. Jay Sullivan, of Phoenix, Ariz., has recently submitted to the Bureau of Mines a sample of high-grade wulfenite concentrates in which that mineral is associated with considerable vanadinite. The property from which these concentrates were derived is said to be situated 4 miles from Kelvin, in Pima County.

The Mohawk mine, which is only a few hundred yards from the Mammoth mine at Schultz (Pl. VI), is said to show considerable quantities of wulfenite in its workings. At the time of the writer's visit the property had not been operated for many years, and the workings could not be examined, as they were not in condition to risk entry. In the shaft house there were a few tons of wulfenite concentrates which had been recovered from the dump by leasers. The writer would estimate that these concentrates contained 15 to 20 per cent molybdic trioxide. The wulfenite was associated with considerable magnetite.

J. M. Kellogg, of Patagonia, Santa Cruz County, owner of the Blue Lead mine 6 miles north of the town, reports that there is a considerable quantity of wulfenite in its ores. The wulfenite is said to be associated with a large amount of pyromorphite.

The Bureau of Mines has received well-crystallized specimens of wulfenite from C. R. Powers, of Gleason, Cochise County. The vein in which this mineral occurs is said to consist of porphyry and to cut a granite formation. The ore shoot, exposed by a shaft 50 feet deep, is reported as being 12 feet wide. The wulfenite is associated with vanadinite and occurs in seams and stringers throughout the ore.

Wulfenite is also said to be a common constituent of the ores of the Tombstone district, Cochise County,^b and in places it occurs in considerable quantities. In Yavapai County it is reported to occur

^a Pratt, J. H., Steel and iron hardening metals: Mineral Resources U. S. for 1903, U. S. Geol. Survey, 1904, p. 342.

^b Austin, W. L., Silver milling in Arizona: Trans. Am. Inst. Min. Eng., vol. 11, 1882-83, p. 105.

in the ores of several prospects in the Bradshaw Mountains;^a also with pyromorphite at the Accidental mine of the Poland Mining Co., of Prescott. The latter property is situated in Lynx Creek Valley near Prescott. The mineral is also said to occur at the Vulture mine in Maricopa County.^b

OCCURRENCE OF MOLYBDENITE AT THE LEVIATHAN MINES, MOHAVE COUNTY.

The molybdenite property of the Leviathan Mines Co. is situated in Copper Canyon, Mohave County, on the eastern slope of the Hual-pai Mountains. It is in the Cedar Valley mining district, about 3 miles southeast of Copperville and about 25 miles east of Yucca, the nearest point on the Atchison, Topeka & Santa Fe Railway. The property is reached from Yucca by a good wagon road to Copperville, thence by trail down Copper Canyon to the claims, which at their low point in the canyon bottom are at an altitude of about 4,000 feet. The country is arid and as vegetation is confined to desert types no timber is available. Fortunately, water for domestic use can be obtained from springs in the canyon and additional supplies for other purposes from the mine seepage. The wagon road from Yucca to Copperville passes over the main range of the Hualpai Mountains, and reaches an elevation of about a mile. The altitude at Yucca is 1,789 feet, and from this point to the base of the mountains on the west the road has only a slight grade, averaging perhaps 1 or 2 per cent, but on the Yucca side of the range proper the grade is about 7 per cent, and on the Copperville side there are grades as high as 11 per cent. Notwithstanding these steep pitches the road is fairly passable, and auto trucks with loads of 4 to 5 tons make the trip from Copperville to Yucca in about two hours.

The Leviathan properties consist of a group of six claims located on two approximately parallel veins known as the "Whale" and the "Copper Wonder." These veins traverse a granite country rock and consist of white quartz carrying molybdenite and chalcopyrite as the principal ore-forming minerals. The strike of both veins is approximately north-south, and they dip between 85° and 90° west. As the granite country rock is more easily weathered than the hard quartz vein material, erosion has left the veins sticking into the air and made their outcrops easily traceable. In some places the outcrop of the Whale vein is 30 to 40 feet high and its outcrop on the south side of the canyon can be seen for miles. Plate VIII shows views of this outcrop, which can be traced for more than 1,500 feet. The Whale vein which is the larger of the two, varies in width from 6 to 40 feet, and the Copper Wonder vein from about 2 to 20 feet.

^a Sanford, S., and Stone, R. W., Useful minerals of the United States: U. S. Geol. Survey Bull. 585, 1914, p. 19.

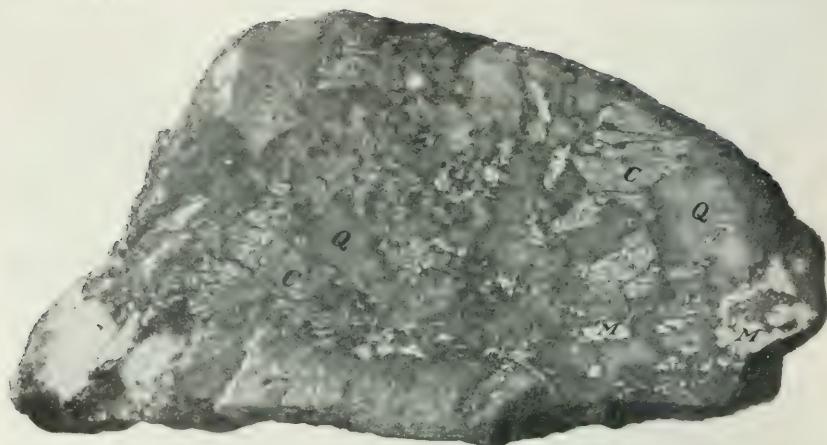
^b Dana, E. S., A system of mineralogy, 6th ed., 1911, p. 991.



A. NEAR VIEW OF OUTCROP OF WHALE VEIN, COPPER CANYON, NEAR COPPERVILLE, ARIZ., SHOWING ITS HEIGHT.



B. OUTCROP OF WHALE VEIN, LOOKING SOUTH. HEADFRAME OF SHAFT AND PART OF WASTE DUMP ARE SHOWN IN MIDDLE FOREGROUND.



A. SECTION THROUGH TYPICAL ORE FROM WHALE VEIN, COPPER CANYON, NEAR COPPERVILLE, ARIZ. (TWO-THIRDS NATURAL SIZE.) M, MOLYBDENITE; C, CHALCOPYRITE; Q, QUARTZ.



B. SECTION OF TYPICAL MOLYBDENITE ORE FROM LEADER MINE, HELVETIA, ARIZ. (ONE AND ONE-HALF TIMES NATURAL SIZE.)

The molybdenite occurs in amorphous and finely crystalline form in thin veinlets and irregular masses throughout the quartz, and as a fine crystalline powder and as nuggets in vugs and cavities in the veins. Much of it is somewhat intimately associated with chalcopyrite, and in only a few places could the writer obtain specimens that were free from copper. In some places, the individual masses of molybdenite and chalcopyrite are large and are separated by masses of quartz, and in other places they may be very small and closely intermingled. Plate IX, A, illustrates a section through a piece of typical ore showing the relation of the two minerals. Where weathering has taken place both the molybdenite and the chalcopyrite have formed alteration products, the former changing to the yellow molybdite, and the chalcopyrite to malachite and azurite. Secondary copper sulphides have also been formed and in several places on the Whale vein native copper occurs. In this vein there are also occasional occurrences of pyrite and small patches of sphalerite, and the ore is reported to carry about 0.02 ounce of gold and 1.4 ounces of silver per ton.

The country rock is a medium-grained gray granite consisting of quartz, feldspar (orthoclase, microcline, and plagioclases varying from albite to labradorite) biotite, muscovite, and small amounts of the usual accessory minerals, zircon and apatite. In the specimen examined there was much zonal development in the feldspar and also much alteration to sericite and possibly kaolin. The rock is more monzonitic in character than the usual granite, but it is a granite nevertheless.

Development work has practically been confined to the Whale vein. At the time of the writer's visit to the property in June, 1915, it consisted of two tunnels driven along the strike of the vein only a few feet above the level of the canyon floor on opposite sides of the gulch, and of a shaft sunk on the north side of the canyon. The tunnel on the south side had been driven for about 210 feet, and that on the north for about 30 feet. The shaft was 100 feet deep and a drift had been driven from the bottom in a southerly direction for 20 feet.

The writer estimates that the average grade of ore exposed in the workings and in the outcrop contains between 2 and 3 per cent MoS_2 , and 1½ to 2 per cent copper. This estimate is substantiated by the results of 22 analyses, each representing samples taken over widths of 2 to 17 feet at various points in the tunnel and shaft and on the outcrop. These analyses, which were kindly furnished the writer by R. C. Jacobson, general manager and engineer of the company, averaged 2.73 per cent MoS_2 , and 1.71 per cent copper, and indicate that the percentages of molybdenum (metal) and copper in the ore are approximately equal. Several rich streaks in the ore body are reported as containing 5 to 8 per cent MoS_2 over widths of 4 to

6 feet. The ore that is richest in molybdenite appears to contain relatively less copper than that of average grade.

No particular difficulty should be encountered in concentrating this ore either by electrostatic or flotation methods, but the concentrates obtained would consist of a mixture of molybdenite and chalcopyrite, probably in almost equal parts, and in that form their molybdenite content would be of little value. A retreatment of the concentrate by any one of a number of mechanical methods would probably separate the greater portion of the copper from the molybdenite (see pp. 94 to 109), but the writer is of the opinion that none of these processes would completely eliminate the copper from a product containing such a large percentage of it. If such is the case, chemical methods of separation must be employed. The results of a concentration test on this ore by the Wood flotation process are given on page 104.

At the time of the writer's visit to the property, surface equipment consisted of a shaft house containing a Western Iron Works 10-horsepower gasoline hoist, a compressor house containing an Alamo 20-horsepower gasoline engine (type S) belted to a Clayton two-drill air compressor, a blacksmith shop, and a cookhouse. The miners were quartered in tents. The little water seeping into the shaft was removed by means of a small Cameron sinking pump, which delivered it when required to a 3,500-gallon galvanized-iron storage tank. This water supply was used for cooling the engine jackets.

It is estimated that the cost of mining will vary from \$1 to \$1.50 per ton, according to the scale on which it is carried on. A water supply sufficient for milling purposes could probably be developed and brought to the property at reasonable cost. Moreover, on account of the location of the mine in a canyon having a considerable drainage area, a considerable quantity of mine water will in all probability have to be pumped with further deepening of the shaft and extension of the workings. This water might be used as a supplementary supply for milling. At present the cost of transportation to and from the railroad at Yucca is high, but if a road were built connecting the claims with the road at Copperville this cost would probably not exceed \$7 or \$8 per ton.

The outcrop of the Whale vein is so exceptionally well defined and so wide and the molybdenite and the copper contents of the vein, as indicated by sampling of the outcrop and workings, are so regular and persistent that the writer considers the property a most promising one notwithstanding the unfortunate association of copper with the molybdenite.

MOLYBDENITE AT THE SMITH & SAWYER AND THE MILLER CLAIMS, MOHAVE COUNTY.

Just below the property of the Leviathan Mines Co. in Copper Canyon and within a distance of 2 miles there are 16 or 17 other well-defined veins, all containing molybdenite associated with chalcopyrite in white quartz, striking in approximately the same direction and having the same general characteristics as those of the Whale and the Copper Wonder veins. Nine claims have been located on these deposits, one group of five claims belonging to Smith & Sawyer, of Kingman, and a group of four owned by J. F. Miller, of Copperville. As far as can be determined from an inspection of their outcrops, the average width of these veins is seemingly 1 to 10 feet and their average content in molybdenite and copper is approximately the same as in the Whale vein, that is, 2 to 3 per cent MoS₂ and 1½ to 2 per cent copper. However, the relative proportions of molybdenite and copper in the different veins seem to vary considerably, but inasmuch as little development work has been done on any of the deposits, this seeming variation may not be true of the veins as a whole but may be solely due to local differences in the individual veins.

The molybdenite in the outcrops of most of the veins has been extensively altered to molybdite, and one of the veins of the Smith and Sawyer group in particular has furnished many remarkably fine crystallized specimens of this mineral. A considerable quantity of bornite was noted in the ore from a vein on the Miller property.

Inasmuch as the mining, concentration, and transportation problems involved in working these veins are identical with those presented by the deposits of the Leviathan Mines Co., they will not be dealt with here.

Considered as a whole, this system of approximately parallel veins on the Leviathan, Smith & Sawyer, and Miller properties constitutes one of the notable molybdenite deposits of the United States.

MOLYBDENITE PROPERTY OF ARIZONA MOLYBDENUM CO., PIMA COUNTY.

The molybdenite property of the Arizona Molybdenum Co. is situated in the northerly end of the Baboquivari Mountains, Pima County, about 35 miles from the railroad at Twin Buttes, the terminal station of a branch line from Sahuarita on the Southern Pacific Railroad. It consists of 10 mining claims of approximately 20 acres each. The ore as represented by a 5-pound sample sent to the writer is seemingly a pegmatite which consists almost entirely of quartz and highly altered feldspar, and throughout which molybdenite, chalcopyrite, and small quantities of galena occur. The ore is reported to contain gold

and silver, and a lot said to be an average sample from a width of 8 feet at one point in the vein is stated to have assayed 2.2 ounces of silver, 1.8 ounces of gold, and 3.9 per cent copper. The vein is reported to be 4 to 10 feet wide and to strike southeast. It is said to traverse a coarse-grained granite. Development on the property consists of three shafts, 36, 40, and 60 feet deep, and of about eight smaller shafts each 10 to 12 feet deep. F. J. Wharton, of Tucson, is the president of the company.

MOLYBDENITE AT LEADER MINE, PIMA COUNTY.

The Leader mine, of the Helvetia Copper Co., is situated near the town of Helvetia, Pima County, at an altitude of about 4,700 feet, on the westerly slope of the Santa Rita Mountains, about 27 miles southeast of Tucson. The main tunnel by which the property is opened runs in a general northerly direction, on the contact of an altered limestone with an underlying granite. In operating the mine for copper a number of years ago, an occurrence of molybdenite was encountered at a depth of about 40 feet in a winze sunk from the tunnel level, about 150 feet in from the portal. At the time of the writer's visit to the property, this part of the winze was inaccessible. The following information regarding the occurrence is taken from a description by Schrader and Hill,^a who visited the mine in 1909.

The winze referred to above is sunk on a quartz vein containing various copper minerals, and dipping at an angle of about 40°. At the tunnel level this vein is only a few inches in width, but there is 1 to 3 feet of mineralized limestone on either side of it, containing chalcopyrite, pyrite, coarse calcite, and quartz, the whole constituting a low-grade copper ore. At a depth of 35 or 40 feet in the winze, molybdenite occurs in both the vein and the surrounding country rock. Eight or ten feet farther down where the dip of the vein flattens the chalcopyrite and pyrite practically disappear, and there is a great increase in the quantity of the molybdenite. At this point there is a body of relatively pure molybdenite ore at least 3 or 4 and perhaps 6 or 7 feet thick. The molybdenite occurs as lenses, irregular bunches, and crystal aggregates associated with both the quartz and the highly altered limestone. Its most common form is as small, flaky crystals.

The rock in which the molybdenite occurs is described as a "dull-brownish and greenish to yellowish mineralized garnetiferous silicified limestone and quartz." It is somewhat massive, and varies from fine to medium grained. It is composed largely of pale-greenish garnet corresponding to grossularite. Quartz is the next most

^a Schrader, F. C., and Hill, J. M., Some occurrences of molybdenite in the Santa Rita and Patagonia Mountains, Arizona: U. S. Geol. Survey Bull. 430, 1910, pp. 156-157.

abundant mineral, with calcite, magnetite (or ilmenite), and epidote present in small quantities as secondary minerals.

Plate IX, *B*, shows a section through a typical piece of molybdenite ore picked up by the writer from a pile of 2 or 3 tons on the dump at the mine. The molybdenite is seen as small flaky crystals (white) scattered through the groundmass of the highly altered rock.

The ore as represented by the small dump above mentioned contains perhaps 5 to 6 per cent molybdenite. Since the writer's visit to the property some development work has been done on the molybdenite ore and a few tons gotten out. In the annual report of the company for 1915 sales of molybdenite ore during the year are said to have netted \$1,891, and it is stated that there were approximately 100 tons of ore in sight that should net about \$26 a ton.^a

OTHER OCCURRENCES OF MOLYBDENITE.

It is reported that a few tons of rich molybdenite ore was taken out several years ago by the Cuprite Copper Co., of Tucson, in mining a large pocket of copper ore on its property in the northwest end of the Santa Rita Mountains, in Pima County. The property is about 8½ miles south of Vail, the nearest point on the Southern Pacific Railroad, and at an altitude of about 4,000 feet. No molybdenite ore in place could be found by the writer in a hasty examination of the mine workings, but several specimens containing 10 to 20 per cent of the mineral were picked up on the mine dump. In these the molybdenite was associated with chalcopyrite and copper carbonates in a gangue of highly altered and silicified limestone. No evidence as to the form of the molybdenite deposit or the possibilities of further occurrences of the mineral could be obtained.

E. O. Stratton, of Tucson, and associates are the owners of a molybdenite property situated on Marble Creek, in the Santa Catalina Mountains, in Pima County, about 20 miles northwest of Tucson and 15 miles south of Oracle. Some promising showings of molybdenite are said to have been encountered in prospect work.

Other occurrences of molybdenite in Pima and Santa Cruz Counties are as follows:

At the Ridley mine, owned by C. B. Ridley, of Helvetia, and situated in the foothills about 1½ miles southwest of that town.

At the McCleary prospects in Madera Canyon, about 10 miles south-southwest of Helvetia and 35 miles south of Tucson.

In the foothill part of Providencia Canyon, about 10 miles northeast of Nogales and 5 miles north of the United States-Mexican boundary line near the Golden Rose and at the Buena Vista mine, the latter

^a Editorial Eng. and Min. Jour., vol. 101, 1916, p. 482.

owned by the Banco del Oro Mining Co., of Magdalena, Sonora, Mexico.

At Duquesne, about a quarter of a mile west of the Belmont mine, on property owned by Capt. O'Connor, of Duquesne.

At the Benton mine and the Line Boy prospect in San Antonio Canyon, about 2 miles south of Duquesne and 15 miles north-north-east of Nogales. The Benton mine is owned by Dennis Coughlin and partners, and the Line Boy prospect by Capt. O'Connor, all of Duquesne.

In all these localities the molybdenite occurs in granite or in quartz traversing the granite. None of the properties has been developed beyond the prospect stage, and present showings do not indicate that any of them are of commercial importance. The above information concerning these occurrences was obtained from detailed descriptions by Schrader and Hill.^a

It is stated ^b that one of the mines of the Santa Nina Co., of Patagonia, has a 6-inch or 7-inch vein of high-grade molybdenite ore in one of their copper mines.

Molybdenite is found in the ores of the Clifton-Morenci district, Greenlee County, in fissure veins with pyrite, chalcopyrite, and sphalerite.^c It also occurs in the disseminated ores at Miami, Gila County, in the primary ores of the chloride district, Mohave County, in a granite-gneiss, and as an original mineral in the ores at the Ray and Kelvin mines in Pinal County.^d

CALIFORNIA.

Although there has never been any commercial production of molybdenum ore in California, molybdenite is widely distributed throughout the State and development work on some of the known occurrences of the mineral will probably prove them to be of economic importance.

Following is a list of deposits that have come to the author's attention. The list includes 41 occurrences of molybdenite in 16 different counties. Brief notes regarding six of these occurrences follow. Wulfenite has been reported in a few localities, principally in the southern part of the State, but as far as known to the writer none of the deposits of this mineral is of commercial interest.

^a Schrader, F. C., and Hill, J. M., Some occurrences of molybdenite in the Santa Rita and Patagonia Mountains, Arizona: Contributions to economic geology: U. S. Geol. Survey Bull. 430, 1910, pp. 154-162.

^b Private communication from J. M. Kellogg, Patagonia, Ariz.

^c Lindgren, W., The genesis of the copper deposits of Clifton-Montmorenci, Arizona: Trans. Am. Inst. Min. Eng., vol. 34, 1905, pp. 515, 523.

^d Sanford, S., and Stone, R. W., Useful minerals of the United States: U. S. Geol. Survey Bull. 585, 1914, p. 16.

Occurrences of molybdenite in California.

Location.	Remarks.	Reference.
Calaveras County: New Big Tree.....	Associated with feldspar.....	Specimen in U. S. National Museum. Do.
Zeila mine.....	Associated with quartz, sericite, and pyrite.	
Eldorado County: Fairplay.....	Small crystals with calcite, chal- copyrite, garnet, and epidote. Flakes up to $\frac{1}{2}$ inch in diameter in white quartz.	Specimen in Agassiz Museum.
Near Red Hill, 9 miles east of Sanger.....	Fair-sized flakes in white quartz.	Specimens in collection of U. S. Geol. Survey.
36 miles northeast of Millwood.....		Specimen in California Bureau of Mines Museum.
Grizzly Flat.....	Large flakes.....	Do.
Fresno County: Kings River Canyon, copper mine.....	Flakes in quartz.....	Do.
Green Mountain, south fork of San Joaquin River.....		Do.
Fresno Flat.....	See p. 62.	Do.
Buchanan prospect, west of Granite Creek, south fork of Kings River.....		
Near Soda Springs.....	In quartz.....	Do.
Inyo County: Bishop, near Hillside Dam, south of Bishop Lake.....	See p. 61.	
White Mountains.....		Do.
West Arm of Death Valley, south of Lida.....		Eng. and Min. Jour., vol. 81, 1906, p. 205.
Kern County: Gold region near Havilah.....		U. S. Geol. Survey Bull. 585, 1914, p. 33.
Near Caliente..... $2\frac{1}{2}$ miles northeast of Rands- burg.....	See p. 63. Deposit said to be 30 feet wide and traced for 2 miles on lime- schist contact.	Eng. and Min. Jour., vol. 96, 1913, p. 186.
Los Angeles County: Northeast part of county.....		Mineral Resources U. S. for 1901; U. S. Geol. Survey, 1902, p. 266.
Los Angeles.....	Associated with feldspar and quartz.	Specimen in U. S. National Museum.
Mono County: 12 miles northwest of Bridge- port, on west fork of Walker River.....	Molybdenite-bearing core about 20 feet wide in quartz vein as- sociated with molybdate.	Mineral Resources U. S. for 1901; U. S. Geol. Survey, 1902, pp. 265-266.
Mono Lake.....	Crystals on quartz.....	Specimen in Agassiz Museum.
Cameron, near Bridgeport.....		Specimen in California Bureau of Mines Museum.
Minnie mine, Sweetwater Range.....	In quartz.....	Do.
Nevada County: Mariposa mine, Rosario district.....		Do.
Mayflower mine, Nevada City.....	Flakes up to 2 inches in diameter in quartz.	Do.
Placer County: Golden Stag mine, Ophir region.....	Small flakes.....	U. S. Geol. Survey Bull. 585, 1914, p. 33.
On Red Mountain, 3 miles north of Cisco.....	Crystalline molybdenite in white quartz.	Specimens in collection of U. S. Geol. Survey.
Riverside County: $4\frac{1}{2}$ miles northeast of Corona.....	See p. 62.	
About 17 miles west of Hemet, in sec. 3, T. 5 S., R. 2 E.....	Fair sized flakes in iron-stained quartz.	Do.
16 miles from Corona.....	In siliceous gangue.....	Mineral Industry, vol. 7, 1898, p. 514.
San Bernardino County: Leasalk.....	Fine grains in white quartz with chalcopyrite.	Specimens in collection of U. S. Geol. Survey.
San Diego County: 40 miles east of San Diego.....	See p. 60.	Specimens in collection of U. S. Geol. Survey.
Near Dulzura.....	Small flakes with quartz and ferro-magnesium minerals.	Specimen in California Bureau of Mines Museum.
Campo.....	In granite.....	Specimen in U. S. National Museum.
Do.....	Associated with feldspar and quartz.	Mineral Industry, vol. 11, 1902, p. 477.
Dewey mine at Grapevine, near Warners Hot Springs.....		Specimen in California Bureau of Mines Museum.
Shasta County: Tom Neal Mountain, 5 miles from Delta.....	In granite.....	Do.
Hazel Creek.....	do.....	U. S. Geol. Survey Bull. 585, 1914, p. 33.
Lamoine.....		

Occurrences of molybdenite in California—Continued.

Location.	Remarks.	Reference.
Tulare County: Three Rivers.....		Specimen in California Bureau of Mines Museum.
California Hot Springs.....	See p. 62.	
Tuolumne County: West of Tower Peak.....	In quartz gangue on a contact of marble and a white schistose pyroxene with epidote and sphalerite.	Turner, Am. Jour. Sci., vol. 5, 1898, p. 427.
South of Knight Creek, north- east of Columbia.	In granite.....	Do.
Ventura County: On Alamo Mountain, north- eastern part of county.	Vein said to be 8 to 15 feet wide...	Mineral Resources U. S., 1901, U. S. Geol. Survey, 1902, pp. 265-266; Eng. and Min. Jour., vol. 72, 1901, p. 337.

**MOLYBDENITE AT PROPERTY OF SANTA MARIA MOLYBDENUM
MINING & MILLING CO., SAN DIEGO COUNTY.**

The property of the Santa Maria Molybdenum Mining & Milling Co., of San Diego, is situated about 40 miles east of that city in the hills to the southeast of the San Pasquale valley and is readily reached from San Diego by automobile, the road being excellent. It is understood to consist of 160 acres of patented ground.

The molybdenite-bearing deposit consists of a large granite dike varying in width from 35 to 100 feet and striking in a general north-easterly direction. The outcrop of this dike is about half a mile long and is particularly well defined. Plate X, A, shows a view looking toward the northwestern end, where the outcrop terminates in an almost perpendicular cliff about 200 feet high. The canyon on which this cliff faces drains into San Pasquale valley which may be seen in the distance in Plate X, A. A good idea of the size of the deposit may be gained from a comparison with the size of the persons shown in the illustration.

The molybdenite occurs sparingly throughout the granite in crystal aggregates and irregularly shaped masses of radial structure, most of which vary in size from one-eighth to 1 inch in maximum diameter. It is associated with a little pyrite. Both the molybdenite and the pyrite have been altered, the former slightly and the latter extensively. In a few instances the transformation of the molybdenite to molybdite has been complete, the latter mineral crystallizing in radial groups, such as are shown in Plate V, B, which illustrates a specimen of molybdite from this property. More often, however, the molybdenite has been only partly altered, resulting in many interesting specimens, one of which is pictured in Plate II, B. The iron oxide formed by the alteration of the pyrite has stained the larger part of the outcropping granite a light red. In this stained part the molybdenite areas are almost invariably surrounded by a narrow rim of unstained rock, as is rather clearly illustrated in Plate



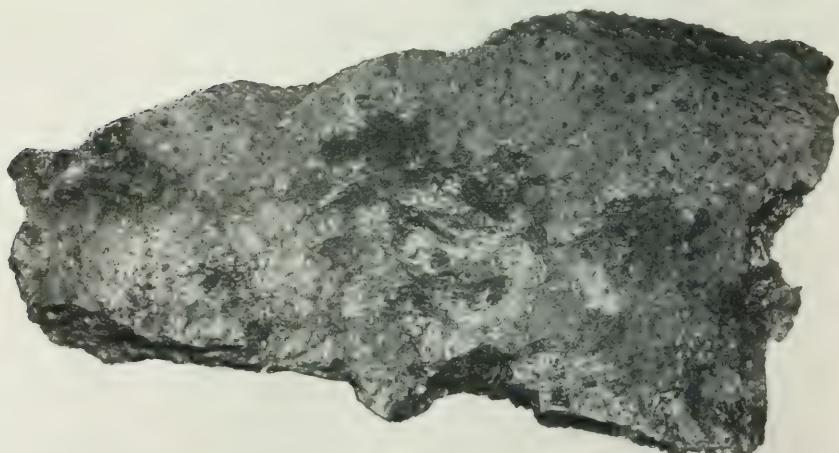
A. OUTCROP OF DIKE ON SANTA MARIA PROPERTY, SAN DIEGO COUNTY, CAL., LOOKING NORTHWEST.



B. OUTCROP OF LOW-GRADE MOLYBDENITE ORE AT PRIMOS MINE, NEAR EMPIRE, COLO.



A. MOLYBDENITE IN IRON-STAINED GRANITE FROM SANTA MARIA PROPERTY, SAN DIEGO COUNTY, CAL. (FOUR-FIFTHS NATURAL SIZE.)



B. MOLYBDENITE IN GRANITE FROM JOHN FLETCHER QUARRY, NEAR CORONA, CAL. (TWO-THIRDS NATURAL SIZE.)

XI, A, which shows a typical specimen of molybdenite ore from the property.

The granite of which the dike is composed is medium grained, and where not iron stained it is light gray to almost white. A microscopical examination of it shows the presence of the following minerals: Quartz, orthoclase, plagioclases varying from albite to oligoclase, biotite, a few minor accessory minerals, and pyrite.

The only development work on the property at the time of the writer's visit in 1914 was five or six open cuts partly crosscutting the dike. Some of them showed ore which might average from 0.25 to 0.5 per cent molybdenite, but from all indications the dike as a whole contains a very much smaller percentage of the mineral. Unless further development work discloses areas richer in molybdenite, the writer does not believe that the occurrence will prove of economic importance. However, as the character of the ore is such that the molybdenite can be readily concentrated into a high-grade product, the discovery of richer ore might lead to successful operations.

A lot of ore weighing 313 pounds, kindly shipped the Bureau of Mines by the owners of the property for concentration tests, and said to be unsorted, assayed 0.47 per cent MoS₂. For the results of hand-picking and concentration tests of this ore, see pages 97 to 99.

MOLYBDENITE NEAR BISHOP, INYO COUNTY.

Specimens of molybdenite associated with molybdite in white quartz have been submitted to the bureau by M. C. Hall, of Bishop. The deposit from which the ore came is said to be situated at an altitude of about 10,000 feet in the Sierra Nevada Mountains about 20 miles from Laws, the nearest station on the Southern Pacific Railroad. There is a road from Laws passable by automobile to within a mile and a half of the property, thence a poor wagon road for a mile, but no road for the last half mile. It is stated, however, that one could readily be built to cover the remaining distance. The outcrop of the deposit is reported to be about 100 feet long and the same distance across. Practically no development work has been done. In a 40-pound sample said to represent average ore, the author would estimate the molybdenite content to be 1 to 2 per cent. With the exception of the occasional occurrence of small grains of chalcopyrite, no minerals other than molybdenite and its alteration product, molybdite, were noted in the quartz. The molybdenite occurs in flakes varying in size from minute specks to an eighth of an inch or more in maximum diameter, and the ore is seemingly of such a nature as to be readily concentrated by either electrostatic or flotation methods. Development work may perhaps prove the deposit to be of economic importance.

MOLYBDENITE AT THE BUCHANAN PROSPECT, FRESNO COUNTY.

Specimens of molybdenite ore have been submitted to the bureau by Paul Buchanan, of Kearney Park, Cal. They are said to have come from a deposit situated on the north side of the south fork of Kings River, between Granite and Copper Creeks, and about 2 miles west of Kanawyer's Camp, in T. 13 S., R. 31 E. The property is difficult of access, being 25 miles or more from the nearest wagon road at Hume, which in turn is a greater distance from the nearest railroad station. The vein in which the molybdenite occurs is reported to have an average width of 1 to 3 feet and to be traceable on the surface for about 3,000 feet, but the outcrop carries molybdenum for only about 2,000 feet. The strike of the mineralized part of the vein is said to be almost north and south. The specimens submitted consist of granite cut by small quartz stringers occasionally containing flakes of molybdenite up to one-fourth inch in maximum diameter. The molybdenite is associated with a small quantity of chalcopyrite. The granite consists of quartz, feldspar, and biotite, and is somewhat iron stained. If the average width of the vein is only 1 to 3 feet, as stated, and the grade of the ore is not richer than the samples submitted, the inaccessibility of the property precludes the possibility of its commercial importance.

MOLYBDENITE NEAR CORONA, RIVERSIDE COUNTY.

An occurrence of molybdenite about $4\frac{1}{2}$ miles northeast of Corona in a granite quarry operated by John Fletcher has been noted by Hess.^a Specimens submitted to the bureau show the mineral to occur in a medium-grained gray granite in flakes up to an inch in diameter. A piece of typical ore is illustrated in Plate XI, *B*. Hess, who visited the deposit in 1907, states that: "The granite is cut by thin pegmatite dikes one-half inch to 2 inches wide. Molybdenite in flakes up to one-half inch across accompanies the dikes in small quantity. In one or two places small flakes may be found in the granite for a distance of 2 or 3 inches from the dikes. The only other metallic mineral found in the dike is iron pyrites in which an assay is said to have shown some copper, gold, and silver." The deposit is said to be small and is probably not of economic importance.

MOLYBDENITE NEAR CALIFORNIA HOT SPRINGS, TULARE COUNTY.

Molybdenite in small flakes up to about one-fourth inch maximum diameter occurs in milky quartz in a large vein about one-half mile from California Hot Springs. This town is about 22 miles west of Ducor, the nearest point on the Southern Pacific Railroad, from

^a Hess, F. L., Some molybdenum deposits of Maine, Utah, and California; Contributions to Economic Geology: U. S. Geol. Survey Bull. 340, 1907, p. 238.

which it is reached by a good automobile road. The deposit is situated in sec. 31, T. 23 S., R. 31 E., at an elevation of about 3,300 feet, and is owned by L. S. Wingrove, of California Hot Springs. Practically no development work has been done on the vein, but a hasty examination of a considerable part of the outcrop indicated to the writer that the occurrence of molybdenite, even as minute specks, is so occasional that there seems to be no possibility of the deposit being of commercial importance.

MOLYBDENITE AT CALIENTE, KERN COUNTY.

J. B. Ferris of Caliente has submitted to the bureau specimens of low-grade gold ore carrying molybdenite in finely disseminated grains, coming from the Golden group of claims a few miles south of the town. The ore body is large, but as determined by samples taken by the author from several places in the tunnels and the drifts by which it is developed, it is so poor in molybdenite as to probably be of no commercial importance as a source of that mineral.

COLORADO.

Molybdenite is widely distributed throughout Colorado, its occurrence having been noted in almost every mountain county. The principal deposits visited by the author are at Red Mountain near Empire in Clear Creek County, and near Climax and Breckenridge in Summit County. A description of these deposits, together with notes as to some of the other occurrences listed in the accompanying table, are given in the following pages.

Several occurrences of wulfenite in the State have been reported, but so far as known these are only of mineralogical interest.

Occurrences of molybdenite in Colorado.

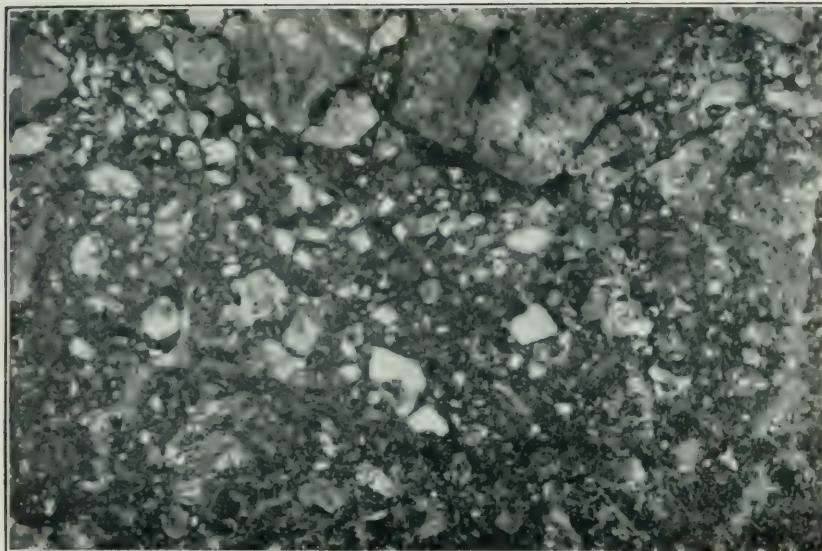
Location of deposit.	Remarks.	Reference.
Chaffee County: Salida.....	In quartz.....	Specimen in Colorado State Museum.
South of Fisher.....	See p. 70.....	Do.
Near Buena Vista.....	See Pl. II, A.....	
Clear Creek County: Red Mountain near Empire.....	See p. 64.....	Dana, E. S., A system of mineralogy, 6th ed., 1911, p. 1042.
Conejos County: At Platoto.....	In spherical forms with concentric structure.	Specimen in U. S. National Museum.
Custer County: Grape Creek.....	In decomposed basic rock with calcite, chlorite, and pyrite. See p. 71.....	Specimen in U. S. National Museum.
12 miles north of Westcliffe.....		
Eagle County: Near Redcliff.....		
Fremont County: Near Rito Alto Peak.....	See p. 70.....	
Gilpin County: 7 miles south of Parkdale.....	See p. 70.....	
From Apex.....	With molybdite.....	Specimen in Colorado State Museum.

Occurrences of molybdenite in Colorado—Continued.

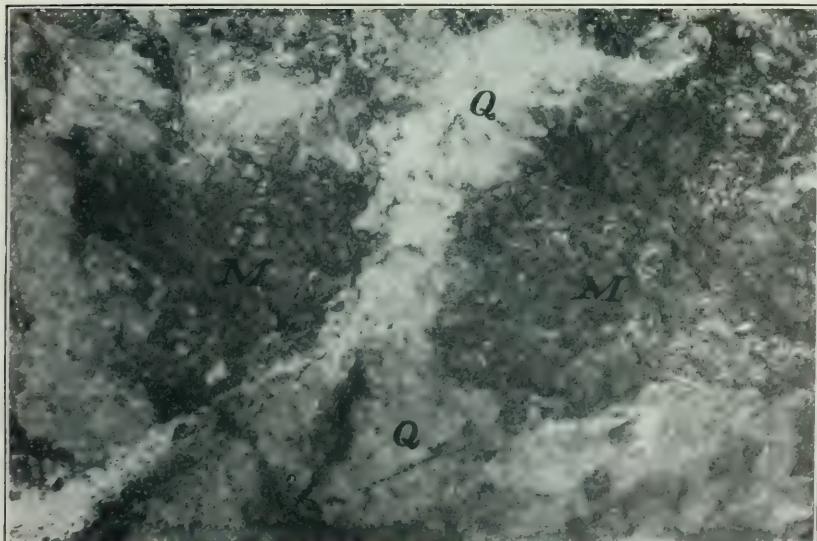
Location of deposit.	Remarks.	Reference.
Gunnison County: 4 miles north of Pitkin near Rock Creek.		Mineral Industry, vol. 6, 1898, p. 485.
At the head of Crystal River near Marble.		Letter from J. C. Hersey, Leadville, Colo.
Near Tin Cup.	Crystalline molybdenite in white quartz.	Specimens in collection of U. S. Geol. Survey.
2 miles from Pitkin.	In quartz veins.	U. S. Geol. Survey Bull. 585, 1914, p. 46.
8 miles southeast of Marble.	See p. 71.	
Huerfano County: 2 miles southeast of Mosca Pass.	Large flakes in float	Letter from John O'Toole, Denver, Colo.
Lake County: In Maid of Erin mine at Leadville; also near the head of Big Evans Gulch.		Eng. and Min. Jour., vol. 80, 1905, p. 127.
Larimer County: 4 miles south of St. Cloud.	See p. 72.	
Ouray County: Engineer Mountain.		Letter from E. C. Weatherly, Ouray, Colo.
Pitkin County: South of Red Mountain.	See p. 71.	Letter from J. C. Hersey, Leadville, Colo.
In Lincoln Gulch southeast of Roaring Fork of the Grand River.	In silicious gangue.	
San Juan County: Between Maggie and Picayune Gulches and Red Peak.	With copper, nickel, and bismuth minerals.	Trans. Am. Inst. Min. Eng., vol. 21, pp. 189-190.
Near Silverton.		U. S. Geol. Survey Bull. 585, 1914, p. 46.
San Miguel County: 1 mile east of Ophir.	See p. 69.	
Summit County: On Bartlett Mountain.	See p. 68.	
On Chalk Mountain.	See p. 68.	
Fremont Pass.		U. S. Geol. Survey Bull. 585, 1914, p. 46.
Near Kokomo.	See p. 72.	
2 miles north of Kokomo.	See p. 72.	
Lenawee mine, between Kingston and Montezuma.		Specimen in courthouse, Breckenridge.
Southern slope of Quandary Mountain.	See p. 67.	
Teller County: Cripple Creek.		

MOLYBDENITE MINE OF PRIMOS CHEMICAL CO., NEAR EMPIRE.

The molybdenite mine of the Primos Chemical Co., near Empire, Clear Creek County, consists of a group of nine claims situated on the eastern slope of Red Mountain, at an altitude of about 10,500 to 12,000 feet. The property is reached from Empire, a station on the Georgetown branch of the Colorado & Southern Railroad, by a good wagon road 14 miles long. The ore-bearing bodies consist of three veins of low-grade ore, the general strike of which, as far as determined by present development work, lies between east by west and northeast by southwest, across the ridge of the mountain. The strikes of the individual veins show a convergence in a westerly direction. Their dip, as indicated by the position of the outcrops with reference to their intersection by a tunnel several hundred feet below, is 50° to 60° in a general northwestern direction. The veins are named from the southeast, and are known as Veins No. 1, No. 2, and No. 3. The ore zone in general; that is, the ground included



A. SECTION THROUGH TYPICAL MOLYBDENITE ORE FROM PRIMOS MINE, NEAR EMPIRE,
COLO. (NATURAL SIZE.)

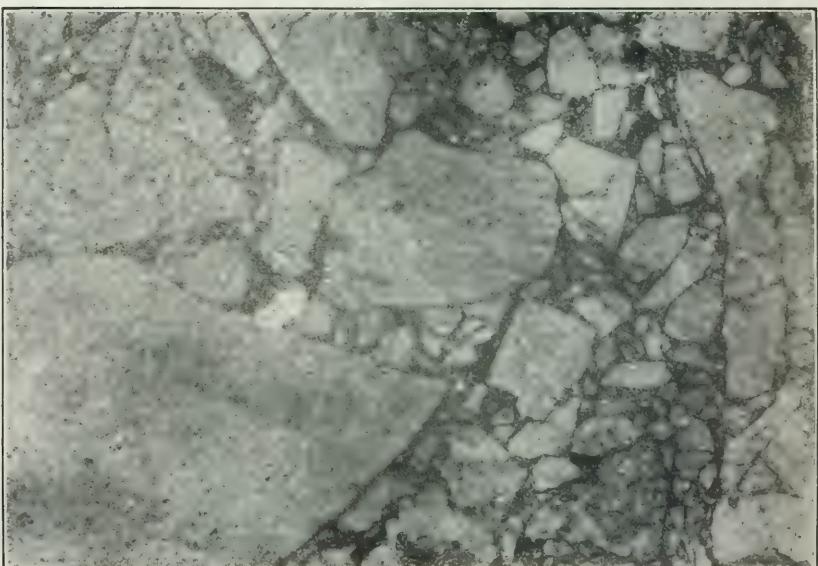


B. TYPICAL MOLYBDENITE ORE FROM BARTLETT MOUNTAIN, SUMMIT COUNTY, COLO.
(NATURAL SIZE.) M, MOLYBDENITE; Q, QUARTZ.



A. VIEW OF RED MOUNTAIN, NEAR EMPIRE, COLO.

The arrow indicates the waste dump at the mouth of the upper tunnel of Primos Mine.



B. SECTION THROUGH TYPICAL MOLYBDENITE ORE FROM GREAT WESTERN MINE, NEAR CHICO, PARK COUNTY, MONT

between the footwall of Vein No. 1 and the hanging wall of Vein No. 3, where cut by the tunnel, is about 200 feet wide. The veins vary greatly in width, both among themselves and along their strikes. Further, they are not particularly well defined, the ore running off into the walls in the form of thin veinlets and stringers.

Vein No. 1 has not been sufficiently developed to warrant even an approximate statement of its average width, but at its intersection by the upper tunnel it is 3 to 4 feet across. Vein No. 2, as exposed by about 1,000 feet of development work, shows a width varying from 3 or 4 inches to 4 or 5 feet, and it has an average width of perhaps 2 feet. Vein No. 2, at its intersection by the upper tunnel, showed 10 feet of ore.

The ore occurs in two forms—one consists of an alaskite (?) breccia in which the molybdenite occurs as occasional small flakes but more often in finely granular form associated with iron pyrite in the interstices of the breccia; in the other the molybdenite occurs in small veinlets and stringers running off into the alaskite-porphry (?) country rock. The brecciated type of ore constitutes the vein material proper, and is well illustrated by Plate XII, A. Oxidation of the molybdenite along the outcrops of the veins has resulted in the formation of considerable molybdite, but the latter mineral disappears entirely with depth. It is stated that the ore contains no copper or other deleterious elements.

The author first visited the property in July, 1913, when development work consisted of only two or three shallow open cuts along the outcrop of one vein. The existence of ore bodies was evidenced, however, by large masses of vein material exposed along the outcrops and by the great quantities of float found throughout the rock slides on the mountain slope below. One of these large masses of outcropping vein material, which showed considerable molybdenite here and there over its entire surface, and was colored in many places by yellow molybdite, is pictured in Plate X, B.

Development of the property was started in earnest in November, 1914, when the present owners obtained control, and to August, 1915, work had been pursued at the rate of about 350 feet per month. At the latter date development consisted of an upper working with 2,500 to 3,000 feet of tunnel, drifts, and crosscuts at two-thirds the distance to the top of the mountain and at an altitude of about 11,800 feet; and also of a tunnel which had just been commenced about 600 feet lower down. The situation of the upper workings is well shown in Plate XIII, A.

The upper workings consist roughly of a main tunnel running in a northwesterly direction for about 500 feet, and of a drift along Vein No. 2 about 800 feet west. Twenty-one crosscuts up to 20 feet in

Contour interval 100 feet

Miles

length have been made along this drift, usually at intervals of about 30 feet, but occasionally at 15-foot intervals. A stope has been started on this vein, and in July, 1915, it had been opened for a horizontal distance of about 40 feet and mined to a height of about 20 feet, the ore having an average width of about $4\frac{1}{2}$ feet. A second and larger stope has been begun to the north of Vein No. 2. The ore body at this point is thought to be either separated from the vein by a large "horse," or to lie on the intersection of veins No. 2 and No. 3. This stope has been mined for a horizontal distance of about 130 feet and to a height of 40 to 45 feet; in width it varies from 6 to 15 feet.

Only a few feet of work has been done on vein No. 1 as the showing of ore encountered at its intersection by the tunnel was poor. Vein No. 3 has been drifted on for about 20 feet on either side of the tunnel, and 10 feet of good ore is said to have been encountered in these drifts.

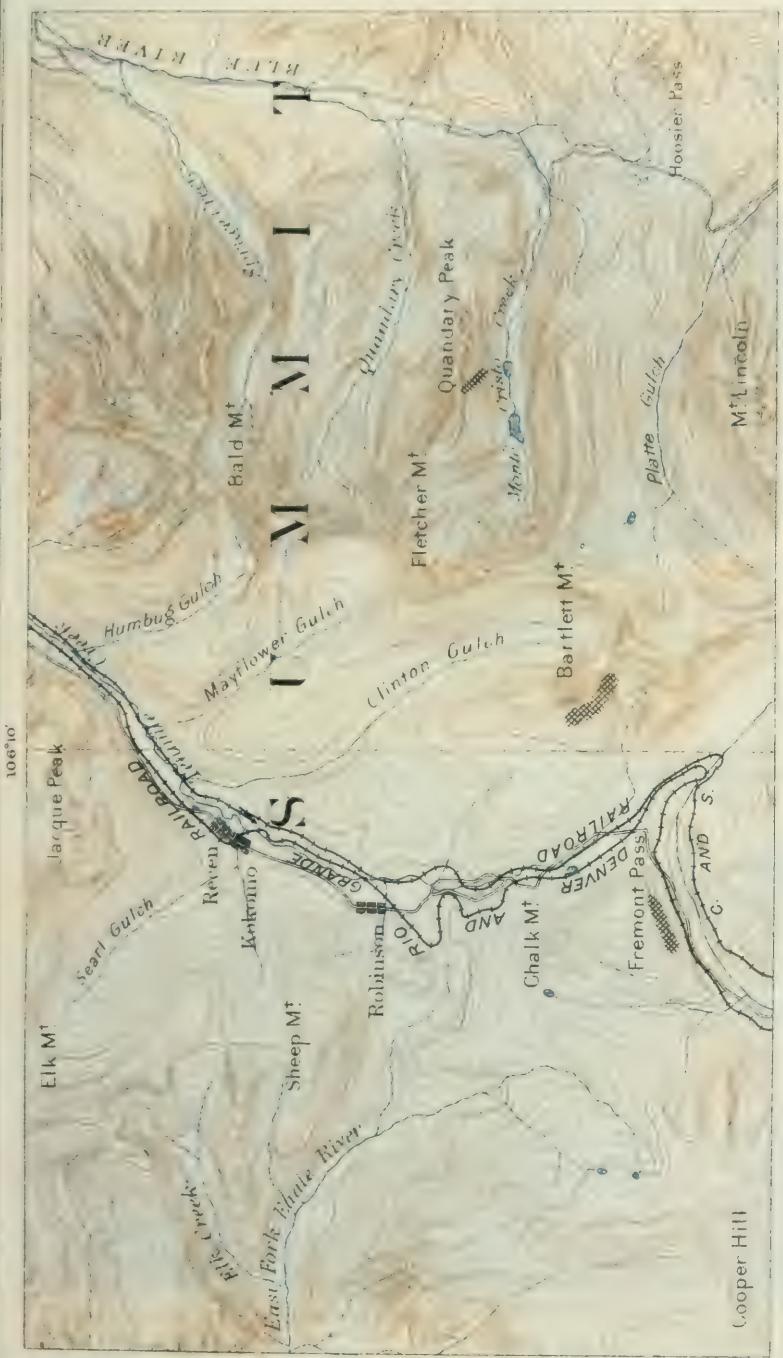
As already stated, work on the lower tunnel was commenced in August, 1915. Assuming that the dip of the veins is 55° and that they will be encountered on this level, over 1,000 feet of backs will be developed by this lower tunnel.

Stoping is carried on largely by hand, as the ground is fairly soft and easily worked. Air drills, however, are used in running the tunnels and drifts.

The ore is trammed to a sorting house at the mouth of the upper tunnel and dumped into a bin from which it is drawn by the sorters as needed. Ore from the bin is screened on small 2-mesh hand sieves. The undersize through the screens is saved and the oversize hand sorted. The rejected oversize is thrown into a car which carries it to the waste dump, and the selected ore is sacked. Filled sacks weigh 75 to 125 pounds each, according to the size and richness of the ore. These are packed down the mountain on mules and stacked near the wagon road. At the time of the author's visit, in July, 1915, the pack train consisted of 14 animals, each of which carried three to four sacks of ore. At the base of the mountain the sacks are loaded onto wagons, weighed, and hauled to the railroad station at Empire, where their contents are emptied into freight cars for shipment to the Eastern plant of the company. From January 1, 1915, to August, 1915, shipments are reported to have averaged two to three carloads of $22\frac{1}{2}$ tons each per week.

The mine has not been in operation for sufficient time and the ore bodies are not well enough developed to justify any statements as to mining cost.

A combined bunk and compressor house, which also contains an office, dining-room and quarters for cooking, is situated about 1,300 feet below the mouth of the upper tunnel and close to the wagon



**MAP OF PART OF SUMMIT COUNTY, COLORADO,
SHOWING LOCATION OF MOLYBDENITE DEPOSITS ON QUANDARY, BARTLETT, AND CHALK MOUNTAINS**

Scale: $\frac{1}{25600}$

0 1 2 3 4 5 Miles

Contour interval 100 feet



A. TYPICAL MOLYBDENITE ORE FROM SALAMANDER CLAIM, QUANDARY PEAK, SUMMIT COUNTY, COLO. (TWO-THIRDS NATURAL SIZE.) *M*, MOLYBDENITE; *Q*, QUARTZ; *Mu*, MUSCOVITE.



B. SCRAPING TAILINGS FOR RETREATMENT TO RECOVER WULFENITE, MAMMOTH, ARIZ.



road. The compressor room in this building contains a 60-horsepower boiler which is fired with wood; it supplies steam for the operation of an Ingersoll-Rand "Imperial" air compressor, type 10. The two steam cylinders on the compressor are 13 by 10 inches and 8 by 10 inches, and the corresponding air cylinders are 14 by 10 inches and 7½ by 10 inches. Although it is rated as a three-drill machine it will operate only two drills at this altitude.

Wood for the boiler is obtained by cutting standing timber in a burned-over area of forest in the vicinity. It is hauled to a small sawmill situated a few hundred yards south of the boiler house, and cut into 4-foot lengths. Stables have been built close to the bunk and compressor house. At the upper tunnel level there is a bunk house and blacksmith shop and the ore-sorting house already referred to.

The production of this property to date has been probably 1,500 to 2,000 tons of ore, averaging approximately 2 per cent molybdenum. In opening the property during the winter months many difficulties were encountered, owing to the altitude and to winter storms.

SALAMANDER AND BLUE VALLEY MOLYBDENITE CLAIMS, NEAR BRECKENRIDGE, SUMMIT COUNTY.

There is an interesting occurrence of molybdenite about 11 miles southwest of Breckenridge, Summit County. The deposit is on the south slope of Quandary Mountain at an altitude of about 12,000 feet (see Pl. XIV), and consists of two pegmatite veins which contain the molybdenite, and on which are two claims known as the Salamander and the Blue Valley. These claims are reached from Breckenridge by a good wagon road for 9 miles up the valleys of Blue River and Monte Christo Creek, thence continuing up the valley of the latter stream for 1½ miles by a poor mountain road, and then across the creek and up the mountain side for half a mile by trail.

At the time of the author's visit to the deposit in October, 1913, a violent snowstorm was in progress, and for that reason his examination was necessarily incomplete.

The pegmatite veins already referred to consist largely of muscovite and quartz with some feldspar, and carry molybdenite and chalcopyrite as accessory minerals, as well as small quantities of molybdate developed by alteration of the molybdenite in places where the latter has been exposed to the air for a considerable time. The veins, which appear to be nearly vertical, traverse a dark-gray micaeous schist or gneiss composed essentially of quartz, muscovite, biotite, and feldspar, and strike in a general northerly direction.

A specimen of typical ore from the Salamander claim is illustrated in Plate XV, A. A sample of about 100 pounds of picked ore, which the author selected as representative of the general grade of concentrating ore that this claim could produce, on analysis showed 4.35

per cent molybdenite and 0.45 per cent copper. The molybdenite occurs in coarsely crystalline aggregates up to $1\frac{1}{2}$ inches in maximum diameter, but on account of its association with chalcopyrite and with such a large percentage of muscovite, it probably could not be recovered in a high-grade concentrate without a rather complex treatment.

On the Salamander claim a tunnel has been run for a distance of 20 feet on the vein, which at this point has a width of 3 to 4 feet.

On the Blue Valley claim there is only a small showing of molybdenite, and no development other than the putting in of several shots at various places along the outcrop. The vein averages only 4 to 6 inches in width and gives no promise of any commercial production of ore.

Directly down the mountain from the claims there is a small lake, and one-half mile farther up the gulch a larger lake at an elevation of 300 or 400 feet above the one first mentioned. Ample water power for all mining purposes could easily be developed from this upper lake, and there is sufficient timber in the immediate neighborhood for all prospective mining needs.

MOLYBDENITE ON BARTLETT MOUNTAIN, SUMMIT COUNTY.

There is a large low-grade deposit of molybdenite ore above timber line at an elevation of approximately 12,000 feet on the southwestern slope of Bartlett Mountain, Summit County. The deposit is about two miles southeast of Robinson, and about a mile and a quarter east of Climax, stations on the Colorado & Southern Railway. Its location is shown in Plate XIV. At the time of the writer's visit to the property in the late fall of 1913 it was covered with snow and little first-hand information concerning the deposit could be obtained. In places where the snow had blown off large quantities of slide rock were exposed, which on an average appeared to contain 0.5 to 1 per cent molybdenite, the mineral occurring in the cracks and fractures of a crystalline quartz, most of which was associated with more or less pyrite, but was practically free from copper minerals. Although most of the deposit was covered with snow, the author had no difficulty in picking up from this particular slide within a few minutes 100 pounds of rock which on sampling and analysis yielded 1.06 per cent MoS_2 . A specimen of typical ore is shown in Plate XII, B.

Eight adjoining claims are reported to have been located on the deposit. The chief development work at the time of the writer's visit consisted of two tunnels, one near the northwestern end of the deposit, on the claims of H. Leal, and the other near the center of the deposit, on the Gillaspey claim, known as "Denver No. 2." The first tunnel had been driven in an eastern direction for a distance of

over 500 feet, and was being pushed ahead with the idea of cross-cutting the deposit. As far as work had progressed the character of the rock seemed essentially the same, and the writer was told that samples taken at frequent intervals throughout the entire length of the tunnel showed an average content of 0.7 per cent MoS₂. The second tunnel was said to be 30 to 40 feet long, but as its portal was closed by a snowdrift it was not entered.

The following notes concerning recent development on the deposit were kindly furnished the writer by Ira Snyder, of Denver, Colo., who has purchased the "Denver No. 2" claim:

The tunnel on the Leal claims has been extended to a total length of 800 feet and at the face a 100-foot drift runs at right angles to the line of the tunnel. No walls have been encountered and there has been no perceptible change in the character or average richness of the ore. A lease is said to have been taken on the Leal claims by Messrs. McDonald, Noble, and King, of Leadville, who have built a wagon road to the property from Climax. These men are also reported to have mined several hundred tons of ore from the claims of Charles J. Senter, near the southeastern end of the deposit, shipping the same to Leadville for concentration by flotation in an experimental plant. The tunnel on the "Denver No. 2" is stated to be now about 75 feet in length, and the ore encountered is reported to contain an average of about 1.3 per cent MoS₂. Experiments on a large scale are being carried on in Denver for concentrating by flotation the ore from this claim. The results of these tests have been satisfactory, and preparations are being made for the installation of a plant at the mine during the coming summer.

MOLYBDENITE NEAR OPHIR, SAN MIGUEL COUNTY.

The Molybdenite Queen claim, owned by G. C. Knox, of Denver, and J. Belisle, of Norwood, Colo., is situated in the Iron Spring mining district about 1 mile southeast of the town of Ophir, which is 2½ miles east of Ophir Loop, a station on the main line of the Rio Grande Southern Railroad. It crosses Nevada Gulch about 600 feet above the creek at the base of the hill and adjoins the Favorite group of gold claims. The deposit is said to consist of a well-defined vein of white quartz 20 to 25 feet wide, traversing a porphyry country rock. The molybdenite occurs in the vein in flaky crystal aggregates and irregular-shaped masses from the size of a pea to pieces three-quarters of an inch or more in diameter. In a 25-pound lot of ore, said to be a sample taken on the surface across the width of the vein, the writer would estimate the molybdenum sulphide content to be 2 to 3 per cent. In this sample considerable alteration of the molybdenite to molybdite had taken place and a small quantity of pyrite was noticed. The ore appears of such character as to be readily concentrated by either electrostatic or flotation methods.

The vein is said to strike in a general southwestern direction, but its dip has as yet not been determined. Practically no development work has been done on the outcrop, but the vein is reported to be cut at a depth of about 600 feet by the Deadwood tunnel and to be approxi-

mately 20 feet wide at the place of its intersection. However, the owners of the property have been unable to verify this statement, as entrance to the tunnel can not be had, owing to a cave-in only a few feet from the portal.^a

OTHER OCCURRENCES OF MOLYBDENITE IN COLORADO.

DEPOSIT NEAR ROBINSON, SUMMIT COUNTY.

A considerable deposit of low-grade molybdenite ore, practically identical with that of Bartlett Mountain described above, is situated on Chalk Mountain near Robinson, Summit County. (See Pl. XIV.) Four claims located on the deposit are owned by E. G. Heckendorf, J. W. Harris, and S. H. Weber, of Denver, and J. A. Weber, of Leadville, Colo. The ore body is reported to be 30 to 40 feet wide, and its outcrop, which runs northeast, is said to have been traced for over 3,000 feet. In October, 1915, development work consisted of seven open cuts, samples from which are reported to have assayed 1 to 3 per cent of molybdenum disulphide.

DEPOSIT NEAR NATHROP, CHAFFEE COUNTY.

Bert Bergstrom and H. C. Hayes, of Buena Vista, Colo., are said to have opened a promising molybdenite property in Chaffee County, a few miles south of Fisher, a station on a branch of the Colorado & Southern Railroad from Nathrop. It is understood that the molybdenite occurs in quartz in flakes up to an inch in maximum diameter and that the ore is practically free from copper minerals. About 1 ton of high-grade molybdenite is reported to have been obtained by careful cobbing and hand sorting of some of the richer ore. It is said that development work on the property is going ahead rapidly.

PROSPECT NEAR PARKDALE, FREMONT COUNTY.

Ralph Fairchild, of Canon City, Colo., has sent the Bureau of Mines specimens of molybdenite ore that is said to occur in considerable quantity in a prospect being developed for copper 7 miles south of Parkdale, Fremont County. The specimens show 5 to 6 per cent of molybdenite associated with pyrite and chalcopyrite in a siliceous gangue. Development work on the property consists of a shaft about 100 feet deep.

An occurrence of molybdenite is reported in Fremont County on the northern slope of Rito Alto Peak in the Sangre de Christo Range. The deposit is above timber line, at an altitude of over 11,000 feet, and is difficult of access, being 18 or 20 miles from Cotopaxi, the nearest station on the Denver & Rio Grande Railroad, and the last 6 or 8 miles of the journey to the property is over a very rough

^a The above information is from a report given the writer by G. C. Knox, of Denver, Colo., on Nov. 8, 1915.

trail. It is understood that the only development work consists of a shaft about 30 feet deep. Specimens of ore said to have come from this occurrence and sent to the writer by B. J. Hillman, of Denver, Colo., consist of a quartzose rock in which the molybdenite occurs as flakes and irregular-shaped masses up to one-half inch or more in diameter and constitutes perhaps 4 or 5 per cent of the whole. The molybdenite is associated with chalcopyrite. No information regarding the size of the deposit nor the general grade of the ore is available.

SPECIMENS FROM WESTCLIFFE, CUSTER COUNTY.

Specimens of molybdenite ore said to be representative of a considerable quantity of material on the dump of an old mine 12 miles north of Westcliffe, Custer County, have been submitted to the bureau by L. H. Schoolfield, of that town. The rock in these specimens is so altered that its identification is impossible. It appears to be a highly metamorphosed calcareous sediment, and, besides the molybdenite, which occurs in flakes up to one-fourth inch in maximum diameter, it contains siderite, calcite, quartz, and some feldspar. It is seemingly free from copper. The writer estimates the molybdenite content of the samples submitted as 2 or 3 per cent.

CLAIM NEAR MARBLE, GUNNISON COUNTY.

The Bureau of Mines has received two samples of molybdenite ore said to have come from a claim recently located by John O'Toole, of Denver, on the southwestern slope of Treasury Mountain, about 8 miles north of Marble, Gunnison County. One sample consists of milky quartz, in which the molybdenite, associated with considerable molybdite, occurs in flakes up to one-quarter of an inch in diameter. In the other sample the quartz is crystalline and the molybdenite more granular in character. Both lots of ore were free from copper minerals and appeared to contain 2 to 3 per cent of molybdenum disulphide. The ore was said to have been taken from two roughly parallel veins about 150 feet apart and striking northeast. The average width of the larger vein was stated to be about 3 feet and that of the smaller about 20 inches.

DEPOSIT SOUTH OF ASPEN, PITKIN COUNTY.

Molybdenite is reported to occur in a deposit owned by F. E. Kendrick and associates, of Leadville, Colo., and situated south of Red Mountain about 20 miles south of Aspen, Pitkin County. The vein, which is called the Green Horn lode, is said to be 6 feet wide. A specimen of ore purported to have come from this deposit consists of a brecciated quartz heavily impregnated with pyrite and containing occasional fine flakes of molybdenite.

CLAIMS NEAR KOKOMO, SUMMIT COUNTY.

G. M. Bacom, of St. Elmo, Colo., has submitted to the bureau samples of molybdenite ore said to have come from a claim near Kokomo, Summit County. The ore consists of white crystalline quartz containing a small amount of fine-grained molybdenite and its alteration product, molybdite. It seems identical with the molybdenite ores from Bartlett and Chalk Mountains which are described above. No information regarding the exact location or size of the deposit is available.

Small quantities of flaky molybdenite occur in ore from the tunnel on claims belonging to Joseph Bryant, of Kokomo, Summit County, and situated about 2 miles southeast of that town. The ore consists principally of quartz heavily impregnated with pyrite.

PROPERTY NEAR ST. CLOUD, LARIMER COUNTY.

E. F. Bartlett, of St. Cloud, Larimer County, has submitted specimens of magnetite containing occasional patches of molybdenite. This ore is said to have come from a property about 4 miles south of the town.

MONTANA.

Out of a dozen or more authenticated occurrences of molybdenum ore in Montana, only two occurrences of molybdenite and one of wulfenite have been examined by the writer. Unfortunately, these deposits were of necessity visited during the late fall when they were covered with snow, which precluded an examination of their outcrops and otherwise hampered their investigation. Besides the occurrences of molybdenite listed in the accompanying table, two occurrences of wulfenite have been reported in the State. One of them is at Radersburg,^a in Broadwater County, and the other is near Twin Bridges, in Madison County. The latter deposit was visited and is described hereafter.

Occurrences of molybdenite in Montana.

Location.	Remarks.	Reference.
Beaverhead County: Head of Birch Creek on Tent Mountain, 12 miles west of Apex and 30 miles northwest of Dillon.	In quartz.....	Mineral Ind., vol. 13, 1904, p. 328, Mineral Resources U. S., 1903, U. S. Geol. Survey, 1904, p. 308, and Mineral Resources, U. S., 1904, U. S. Geol. Survey, 1905, p. 341.
Wise River.....	See p. 76.....	Letter from F. W. Hall, Wise River, Mont.
Broadwater County: At Winton.....	With calcite and vesuvianite.....	Specimen in U. S. National Mu- seum.
Fergus County: At Neihart.....		U. S. Geol. Survey Bull. 585, 1914, p. 112.

^a Specimen in Harvard collection, Agassiz Museum.

Occurrences of molybdenite in Montana—Continued.

Location.	Remarks.	Reference.
Jefferson County: At Clancey..... Near Homestake.....	With feldspar, quartz, chalco-pyrite, and muscovite.	Specimen in U. S. National Museum. Mineral Resources U. S., 1906, U. S. Geol. Survey, 1907, p. 528; Eng. and Min. Jour., vol. 76, 1903, pp. 370, 791.
Madison County: Near Sheridan.....		Mineral Resources U. S., 1906, U. S. Geol. Survey, 1907, p. 528.
Missoula County: Leslie Copper Mine in western part of county.....	In quantity on 150-foot level.....	Mineral Resources U. S., 1901, U. S. Geol. Survey, 1902, p. 266.
Park County: Near Chico Hot Springs..... Near Cooke, at head of Still-water River.....	See p. 73..... See p. 76.....	
Powell County: In Carpenter Gulch, 2 miles east of Ophir.....	See p. 75.....	Mineral Resources U. S., 1903, U. S. Geol. Survey, 1904, p. 308, and Mineral Resources U. S., 1904, U. S. Geol. Survey, 1905, p. 341.
Silverbow County: In the Montgomery, Altoona, and neighboring claims and number of places east of the Flat and in the Gagnon mine.....		Weed, W. H., Geology and ore deposits of the Butte district, Montana: U. S. Geol. Survey Prof. Paper 74, 1912, p. 79.

MOLYBDENITE NEAR CHICO HOT SPRINGS, PARK COUNTY.

The molybdenite property of the Great Western Mining & Milling Co. is situated in Park County about $6\frac{1}{2}$ miles from Chico Hot Springs and $5\frac{1}{2}$ miles southeast of Chico. It is at an elevation of about 7,500 feet on the northeast bank of Emigrant Creek opposite Emigrant Peak, and on the southwest slope of the ridge joining Chico Peak and Mineral Mountain, outlying peaks of the Absaroka Range.

The property is about 10 miles from Emigrant, the nearest railroad point on the Yellowstone Park branch of the Northern Pacific Railroad from which it is reached by wagon road via Chico Hot Springs and Chico. From Emigrant to Chico this road is in fair condition and there are no bad grades, but up Emigrant Creek the road rises almost continuously and many of the grades are so steep that the hauling of even moderate loads is accomplished with difficulty.

The deposit consists of a vein of what is seemingly a brecciated and somewhat altered fine-grained light-gray porphyry in which fine-grained molybdenite intimately associated with pyrite forms the matrix and permeates the individual fragments of brecciated material. Plate XIII, B, illustrates a cross section of typical ore from the deposit. According to Iddings and Weed^a the rocks downstream from the mine consists of basic andesitic breccia and flows, whereas above the mine they are acid porphyrites, andesite, and dacite. At the time the writer visited the property, in the late fall of 1913, the outcrop of the vein was covered with snow and the underground

^a Iddings, J. P., and Weed, W. H., Livingston folio (No. 1), Geol. Atlas U. S., U. S. Geol. Survey, 1894

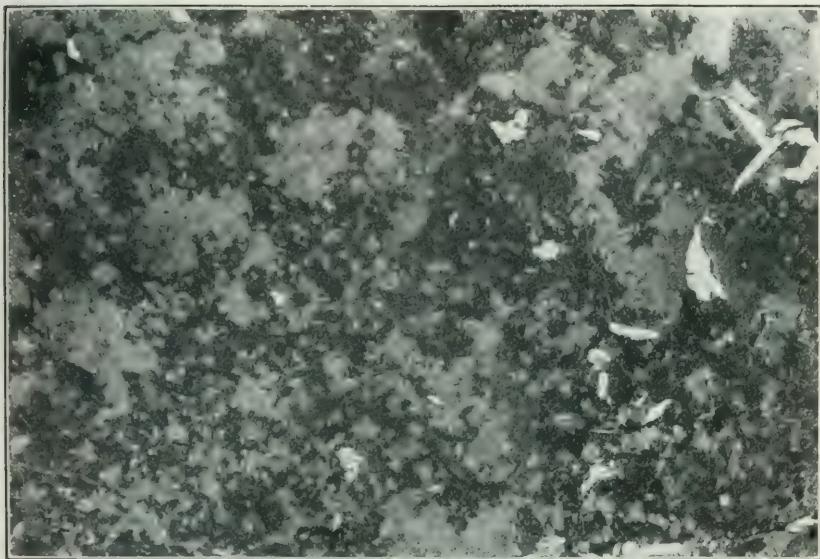
workings were inaccessible owing to the presence of a great quantity of carbonic acid gas. As the writer was unable to make an examination of the workings, H. F. Lawrence, the mine manager, kindly supplied the following notes:

The molybdenite deposit was cut many years ago by a tunnel driven in search of gold. This old tunnel (said to be 700 to 800 feet long but the face of which is inaccessible owing to cave-ins) intersects the molybdenite-bearing vein 360 feet from the portal and at a vertical depth of about 260 feet below the outcrop of the vein. At the point of intersection by the tunnel the vein is about 14 feet wide and so nearly perpendicular that it is impossible to say which is the foot and which the hanging wall. Only one wall is well defined. There is practically no development work on the vein at the tunnel level, only a few feet of drifting having been done and a raise started. The strike of the vein is approximately N. 30° W. by S. 30° E. It has been traced on the surface for over 1,000 feet by means of open cuts, and float ore indicates that it continues much farther. The average width of the outcrop is 12 to 15 feet.

As regards the molybdenite content of the ore, the author was informed by E. C. Sackett of Livingston, Mont., that two samples taken by him across the drift in the tunnel assayed 14 and 23 per cent MoS_2 , respectively, but these samples were probably taken in the richest places that could be found. As indicated by several tons of ore in a small mill erected for experimental concentration work near the mouth of the tunnel, the ore in the drift is of good grade, averaging perhaps 5 to 6 per cent MoS_2 . As far as shown by tests in a few small specimens, the ore contains no copper.

At the time of the writer's visit 10 to 12 men were employed in gathering a fuel supply for winter. A new boarding house had just been completed and the foundation for a mill erected, and active development work was contemplated within a few weeks. It was proposed to treat the ore by water flotation without the use of acid or oil on machines designed by George B. Allison, president of the company. Whether the proposed process of treatment will be successful can not be foretold, but from a number of concentration tests on a model machine, which the writer saw made at Butte, Mont., it appears to be impossible to obtain a high-grade concentrate (85 per cent or more MoS_2) from the ore by the process contemplated. The association of the molybdenite with the gangue is intimate and it is stated that the ore must be crushed through a 60-mesh to 80-mesh screen before the molybdenite is liberated. It is practically impossible to feed this fine material to the water surface in an ore sheet only one mineral particle in depth, and for this reason considerable fine silica is supported on the floating film of molybdenite. A part of the pyrite in the ore also floats, and both of these impurities detract considerably from the grade of the concentrates.

Plenty of wood for both fuel and mine timbers can be obtained in the immediate vicinity of the mine, and Emigrant Creek carries sufficient water to supply a large mill.



A. SECTION THROUGH MOLYBDENITE ORE FROM QUIGLEY MINE, CARPENTER GULCH,
NEAR OPHIR, POWELL COUNTY, MONT. (SLIGHTLY ENLARGED.)



B. SECTION THROUGH MOLYBDENITE ORE FROM ROMERO MINE, PORVENIR, SAN MIGUEL
COUNTY, N. MEX. (TWO TIMES NATURAL SIZE.)

Inquiries addressed to the president of the company as to the progress made in development work have not been answered; hence the author can not state what the result of this work was or whether it was ever carried out as contemplated.

MOLYBDENITE IN CARPENTER GULCH, POWELL COUNTY.

There is an occurrence of molybdenite ore about 2 miles east of Ophir, in Carpenter Gulch, Powell County. The property, which is owned by Thomas L. Quigley, of Sacramento, Cal., is about $7\frac{1}{2}$ miles from Avon and 12 miles from Elliston, stations on the Northern Pacific Railroad, from which it is reached by wagon road. The elevation of the mine is approximately 5,700 feet. The author visited the property in the late fall of 1913, when the outcrop of the deposit was covered with snow. Apparently the property had not been worked for several years, and the portal of the tunnel by which it was developed was locked. Furthermore, the tunnel had caved badly near the portal, so that access to it could not be had. By clearing away the snow from a part of the dump the writer was able to obtain 30 or 40 pounds of ore, containing perhaps 2 or 3 per cent of molybdenite in flakes and irregular-shaped masses up to an inch in maximum diameter. The rock in which the molybdenite occurs is seemingly a metamorphosed limestone that has undergone various stages of alteration. Some specimens are much more highly altered than others. The great differences in the character of individual specimens of the ore are illustrated by Plate XVI, A, which also plainly shows how the molybdenite occurs. The most prominent minerals in the rock are garnet, epidote, quartz, some unidentified silicates, and one or more calcareous carbonates. The ore is seemingly free from copper minerals.

Tests of the crushed ore show that the garnet contained in it is a good conductor of electricity, and therefore concentration by electrostatic methods is impracticable, but the ore is evidently suitable for treatment by flotation. From the size of the dump at the tunnel mouth the writer would estimate that the tunnel had been projected between 150 and 200 feet, but as the tunnel was inaccessible for the reasons stated above nothing definite can be said here as to the size of the deposit and of the possibilities of its being of commercial importance.

A second occurrence of molybdenite in Carpenter Gulch is reported at the head waters of the creek, about $2\frac{1}{2}$ miles above the occurrence already noted.^a Specimens said to have come from this deposit show the molybdenite occurring in small flakes in what is seemingly a metamorphosed limestone.

^a Letter, dated Mar. 6, 1915, from C. L. Smith, Deer Lodge, Mont.

OTHER MOLYBDENITE OCCURRENCES IN MONTANA.

The Bureau of Mines has received from G. H. Gibson of Cooke, Mont., several samples of molybdenite ore said to have come from a deposit on the headwaters of the Stillwater River near Cooke, Park County. The samples consist of greenish-black, medium to coarse grained garnetiferous amphibolite in which the molybdenite occurs in small irregularly distributed patches. The rock is heavy and tough, and at least 75 per cent of it is made up of dark-green hornblende. The other principal constituents are a reddish-brown garnet and quartz, the latter occurring for the most part in narrow veinlets. Pyrite occurs associated with the molybdenite both in the hornblende and in the garnet. In the 30 or 40 pounds of material submitted to the bureau the author would estimate the molybdenite content to be 1 to 1.5 per cent.

B. R. Holland of Cooke, Mont., has sent in specimens of quartz containing small flakes of molybdenite associated with molybdite. These are said to have come from a prospect in the vicinity of that town.

Specimens of molybdenite ore, said to have been obtained from stringers and small veins cut in driving a tunnel in Comet Mountain on the property of the Boston-Montana Development Co., Beaverhead County, have been received from F. W. Hall, of Wise River, Mont. The molybdenite occurs as small flakes in quartz and is stated to occur in quantity.^a

WULFENITE ORE NEAR TWIN BRIDGES, MADISON COUNTY.

The property of the Grand View Mining & Development Co., of Twin Bridges, Mont., is situated near the crest of the Tobacco Root Range, about 11 miles east of Twin Bridges, the nearest station on a branch of the Northern Pacific Railroad from Whitehall. It is situated near the summit of Little Baldy Mountain and is reached by wagon road up Goodrich Gulch from Twin Bridges.

The deposit consists of a vein of porous and well-crystallized cerussite heavily impregnated with iron oxide and containing perhaps $\frac{1}{2}$ to 1 per cent of well-crystallized wulfenite. The ore is reported to carry 30 to 50 per cent of lead, 2 to 6 ounces of silver, and 0.2 ounce to 1.5 ounces of gold per ton.

At the time of the author's visit to the property in the late fall of 1913 little development work had been done, and the outcrop of the deposit was covered with several feet of snow, so little exact information as to the size and extent of the deposit could be obtained. A short tunnel had been driven only a few feet below the outcrop, and intersected the vein at a point where it was 17 feet horizontally be-

^a Letter of Dec. 9, 1914, from F. W. Hall, Wise River, Mont.

tween walls, and a few feet of drifting had been done on the vein at this point. The strike of the vein as indicated by this work was practically east, and the dip appeared to the author to be about 35° to 40° to the north. However, the management of the property seemingly has a radically different idea as to the dip of the deposit, because the company has started a tunnel several hundred feet below, on the south side of the mountain, and is driving it north to intersect the vein, whereas if the deposit dips in the direction the author supposes the vein could be much more readily reached by a tunnel from the north side of the mountain. In the upper workings black limestone seems to form both the footwall and the hanging wall of the deposit.

A microscopic examination of a large dark-colored wulfenite crystal, said to have come from this deposit and given to the author by Henry Schmidt, president of the company, showed the presence of metallic gold in the crystal, the occurrence being seemingly similar to that of the native metal in wulfenite crystals from the Old Yuma mine near Tucson, Ariz. (see p. 115).

Because of the small amount of development work on the property, it is impossible to say whether the occurrence of wulfenite in the ore may prove of commercial importance as a source of molybdenum. However, if concentration of the ore is attempted with a view to saving the wulfenite, great difficulty is almost certain to be encountered in separating it from the cerussite, which is nearly of the same specific gravity.

NEW MEXICO.

Few occurrences of molybdenite have been reported in New Mexico, and only one deposit in the State, that of the Romero Mining Co., near Porvenir, San Miguel County, has been visited by the author. Other occurrences are at Rociada, about 6 miles north of Porvenir, in the same county; at Bromide, in Rio Arriba County; and at the Modoc mine, in the Fierro district, Grant County. In all these localities the molybdenite is associated with copper ores.^a

The mineral also occurs in quartz breccia in a deposit near Magdalena, Socorro County,^b and associated with lead and silver ores at Organ, Dona Ana County.^c

Deposits of wulfenite are confined almost entirely to Dona Ana, Sierra, and Grant Counties, in the southwestern corner of the State. The mineral occurs rather commonly with silver ores in the Organ district, in Dona Ana County, and many well-crystallized specimens have been obtained from the Bennett mine at Organ. Most of these specimens show beautiful yellow crystals of wulfenite associated with

^a Sanford, Samuel, and Stone, R. W., Useful minerals of the United States: U. S. Geol. Survey Bull. 585, 1914, p. 132.

^b Specimens in collection of Bureau of Mines.

^c Sanford, Samuel, and Stone, R. W., loc. cit.

cellular quartz and secondary calcite and limonite. In Grant County the mineral occurs in deposits near Lordsburg^a and also in the Lucky Bill mine near Santa Rita, but as far as known these occurrences are only of mineralogical interest. Plate IV, *B*, shows a group of wulfenite crystals of unusual form from the Lucky Bill mine. In Sierra County wulfenite has been mined at Hillsboro,^b and a small production of the mineral was derived by Mr. Ralph Widener in 1914 from the Gladys claim, in the Caballos Mountains,^c near Cutter. The occurrence of the mineral has also been reported from the Belcher mine, in Santa Fe County.^d

MOLYBDENITE PROPERTY OF THE ROMERO MINING CO.

The Romero Mining Co., of Las Vegas, has done considerable development work on a molybdenite prospect situated about a mile and a half from the Porvenir Hotel at Porvenir, San Miguel County. This town is about 18 miles northwest of Las Vegas, and may be reached from there over a good wagon road or over a part of the same road from the northerly terminal of the Hot Springs Railroad, from which it is about 8 miles distant.

The vein material of this deposit is seemingly a pegmatite, consisting largely of quartz and feldspar, with smaller amounts of biotite and occasionally fluorite. The molybdenite, which is closely associated with chalcopyrite, occurs in masses up to 2 or 3 inches in maximum diameter in occasional pockets in the vein material. The ore also contains scheelite, bismuthinite, malachite, molybdite, and various iron oxides. Plate XVI, *B*, illustrates a cross section of a specimen of molybdenite ore from this property. The interesting ore structure shown, although not typical of the ore as a whole, was noted in a number of specimens. The country rock is a fine-grained pink feldspathic granite, which upon microscopic examination shows the following minerals: Quartz, orthoclase, microcline (very abundant), albite, a small amount of biotite, and a few minor accessory minerals.

When the author visited this property, in the winter of 1913, it was covered with snow and the outcrop of the deposit could not be examined. At that time development work consisted of a tunnel about 700 feet long and a shaft said to be about 75 feet deep. The bottom of this shaft was filled for 20 feet or more with material that had caved from the sides. Twenty or thirty tons of rich molybdenite ore associated with tungsten, bismuth, and copper minerals was reported to have been taken from several pockets in this shaft, but at the time of the author's visit there was no ore visible either in the

^a Sanford, Samuel, and Stone, R. W., op. cit., p. 134.

^b Sanford, Samuel, and Stone, R. W., loc. cit.

^c Hess, Frank L., The production of cobalt, molybdenum, nickel, etc.: Mineral Resources of U. S. for 1914, U. S. Geol. Survey, 1915, p. 925.

^d Specimen 84293 in U. S. National Museum.

shaft or in the tunnel, which was being driven with the expectation of crossecutting the ore-bearing pegmatite at depth. A considerable part of the rich ore taken from the shaft was sacked and stored in a small experimental mill that had been erected near the property. A part of it had been treated by crushing, followed by screening and hand picking to remove the coarser pieces of molybdenite, followed by concentration on a Wilfley table. The author was shown several small lots of coarse high-grade molybdenite and several tons of concentrates containing about 7 per cent MoS₂ and rich in copper, which was obtained by this method of treatment. It was stated that tests to recover the molybdenite and copper by means of an oil-flotation process tried on an experimental scale at the mill had resulted in failure. It is understood that a few hundred pounds of coarse high-grade molybdenite, which presumably was recovered from some of the sacked ore in storage at the time of the author's visit, was sold by the company in 1914.

WASHINGTON.

CROWN POINT MINE.

The Crown Point mine of the Aurelia Crown Co. of Seattle is situated in the Chelan National Forest, in the NW. $\frac{1}{4}$ T. 31 N., R. 16 E., at the head of Railroad Creek, Chelan County. It is near the summit of the Cascade Range at an elevation of over 5,000 feet. (See accompanying sketch map, fig. 1.) The property is reached from Chelan Falls, on the Great Northern Railway, via stage to Chelan or Lakeside, a distance of 3 or 4 miles, thence by steamer up Lake Chelan for about 40 miles to Lucerne, and then by wagon road and trail up Railroad Creek for about 18 miles. The first 3 or 4 miles of this last part of the journey are over a poor wagon road which ascends the hill back of Lucerne with many steep grades and sharp curves to connect with an abandoned railroad grade which continues up the north bank of the creek to a point about 12 miles from its mouth. From the up-stream end of the railroad grade a poor trail leads to the property, about 6 miles distant. The elevation of Lake Chelan at Lucerne is 1,072 feet. Accordingly the vertical rise from the lake to the mine is about 4,000 feet, and the average grade of the road and trail for the entire 18 miles is over 4 per cent.

The molybdenite-bearing deposit at the Crown Point mine consists in the main of a nearly horizontal vein of white vitreous quartz, which outcrops for a distance of several hundred feet on the northeast face of an almost perpendicular granite cliff at a height of 700 or 800 feet above its base. This vein dips slightly (perhaps 5° to 6°) west. On the outcrop its maximum thickness is about 3 feet, and it pinches gradually to 3 or 4 inches at both ends of the outcrop. The vein also decreases rapidly in thickness as it runs back into the cliff, and

in a distance of 75 to 100 feet it practically pinches out. Plate XVII, A, shows the outcrop at the mouth of one of the short tunnels by which the property is developed. Attention is called to the pinch of the vein toward the left as it runs into the cliff and to the well-defined footwall and hanging wall. The old tree stub at the right leans out from the face of the cliff, which drops almost perpendicularly from the mouth of the tunnel for 600 or 700 feet.

An inspection of the local topography makes it evident that the hill in which the vein occurs once extended much farther to the northwest, and that a considerable part of it has been removed by erosion to form the valley on which the present cliff faces. It is certain

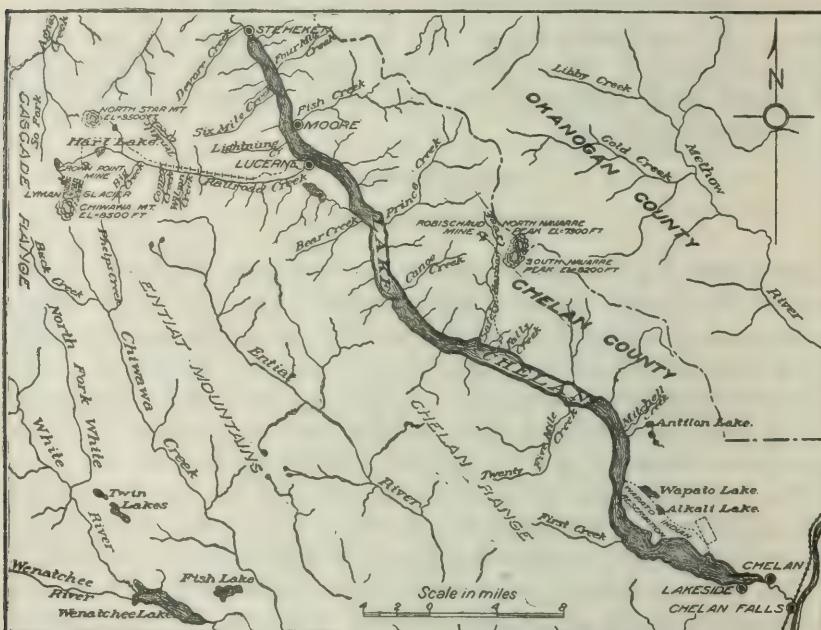


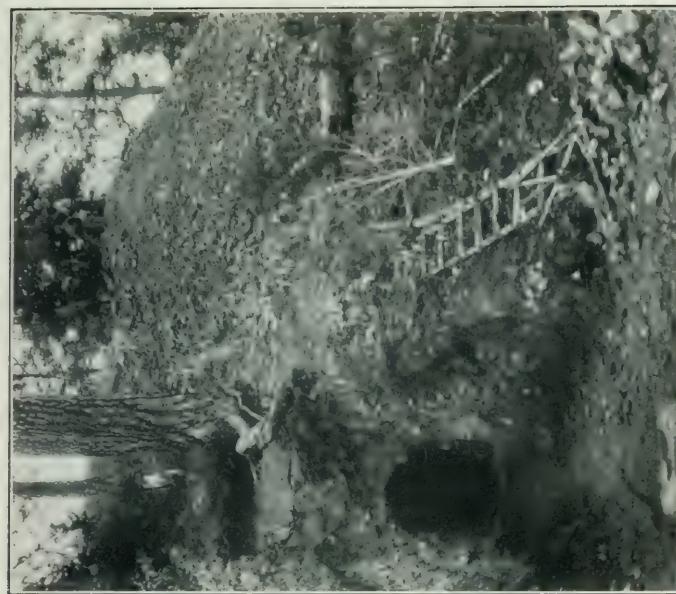
FIGURE 1.—Sketch map of the vicinity of Lake Chelan, Wash., and vicinity, showing the situation of the Crown Point and Robischand mines.

that the molybdenite-bearing vein extended into this eroded part, but there is no evidence from which to determine how much of the vein has been carried away.

The molybdenite occurs scattered irregularly through the quartz in masses ranging in size from minute specks to pieces 4 to 5 inches in maximum diameter. In general the molybdenite is unusually well crystallized, and the deposit probably affords finer specimens of the mineral than are to be obtained from any other known occurrence. Most of the crystals have the form of flat, hexagonal pyramids, the majority of which are beautifully striated. Some of them are one-half to 1 inch high, and 4 to 5 inches in maximum diameter, and weigh one-fourth to one-third of a pound each. The contrast afforded



1. OUTCROP OF UPPER VEIN AT MOUTH OF TUNNEL NO. 1,
GROWN POINT MINE, RAILROAD CREEK, CHELAN COUNTY,
WASH.



2. LOWER TUNNEL AND DUMP FROM UPPER WORKINGS, STARR
MINE, NEAR LOOMIS, OKANOGAN COUNTY, WASH.

by these lustrous black crystals on a background of clean white quartz is strikingly beautiful. Photographs of some of these crystals and of a characteristic ore from this deposit are reproduced in Plates I and III, A. A few masses of molybdenite larger than those mentioned above are found, and the company states that "some have been mined that weighed over 5 pounds," and that "one weighed 11 pounds." In general, the molybdenite does not occur in the center of the vein, but is confined to horizons extending from a line 2 to 3 inches from the center of the vein to a line the same distance of either wall. The accessory minerals are unimportant. Small quantities of chalcopyrite and copper carbonates derived from it occur at several places in the vein, also occasional small patches of galena and sphalerite. These minerals are, however, largely confined to occurrences along the walls or in the immediately adjoining country rock. On the whole, the quartz-vein material is remarkably free from all minerals except molybdenite. In several places along the outcrop and in the tunnels where molybdenite is exposed to the air it has altered to molybdite, and fine specimens of partly altered crystals may be obtained.

The country rock is a medium to fine grained, greenish-gray biotite granite in which the feldspars are kaolinized to a considerable extent. The biotite is also more or less altered and is in various stages of chloritization. According to analyses made by Zaumbrecker and Pierce,^a of Northwestern University, the country rock does not contain molybdenum. Crook, in describing the occurrence of molybdenite at this mine,^b cites the absence of molybdenum in the neighboring granite as an indication that the molybdenite in the vein has not been derived by lateral secretion.

About 10 feet immediately below the vein already described and roughly parallel with it there is a second smaller quartz vein which outcrops for a short distance along the face of the cliff. The vein is only a few inches in thickness, but it is said to be richer in molybdenite than the larger vein. Little development work has been done on it, and nothing can be said of its possibilities.

Development work on the upper vein consists of two short intersecting tunnels. The larger of these, locally known as Tunnel No. 1, runs about 200 feet west and is intersected at an acute angle by Tunnel No. 4, which is about 80 feet long and runs southwest. The author's examination of the property was of necessity confined almost entirely to an inspection of the upper vein as disclosed by these two tunnels, as a heavy snowstorm, in progress at the time of his visit, rendered work along the outcrop on the face of the cliff impossible.

^a Crook, A. R., Molybdenite at Crown Point, Washington: Geol. Soc. of America Bull., vol. 15, 1904, p. 287.

^b Crook, A. R., op. cit., pp. 283-288.

Equipment to serve the Crown Point and neighboring claims controlled by the same owners consists of a mill, machine shop, power house, sawmill, warehouse, three cabins, and a barn. The mill is situated on the slope at the foot of the cliff in which the molybdenite-bearing veins occur, and is connected with the tunnels above by an aerial tram. As the property had been closed for the winter at the time of the author's visit, entrance to the mill was not to be had, and no detailed description of its contents can be given here. The equipment is said to consist of crushing and concentrating machinery, the latter including a Schule dry concentrator imported from Hamburg, Germany, for treating the molybdenite ore.^a The mill building also contains a small compressor plant operated by a Pelton wheel. The president and general manager of the company in speaking of the mill stated: "All the machinery works well except the Schule concentrator, which does not save the small particles of molybdenite; neither does it entirely separate all the quartz from the molybdenite we have concentrated."

There is a splendid supply of timber available for use in mining or building. About half of this is Douglas and white fir and the remainder consists of cedar, white and yellow pine, spruce, and hemlock. As already stated, the property lies within the boundaries of the Chelan National Forest: hence stumpage is for sale by the United States Government.

Much water power could be developed from a number of sources in the immediate neighborhood. Principal among these is Aurelia Lake, which has an area of about 80 acres, and is said to be capable of supplying water with a head of more than 1,600 feet within the confines of the property.

The mine is credited with a production of 10 to 12 tons of molybdenite ore in both 1901 and 1902.^b Presumably this was high-grade material, although no statement regarding its quality is made. After leaving the property the author saw at the warehouse of the company at Lucerne about $2\frac{1}{2}$ tons of high-grade mineral estimated to contain over 95 per cent MoS₂, which was ready for shipment. This material was said to have been obtained by hand cobbing the ore and picking out the larger pieces of molybdenite.

The cost of mining at the property is considerable on account of the high cost of transporting supplies and the narrowness and slight dip of the ore body. The granite in which the vein occurs is hard and at least 3 or 4 feet of it must be mined. However, the vein stands up fairly well after the underlying granite has been removed, and with careful selective mining little sorting would be necessary, and the

^a Editorial, Eng. and Min. Jour., vol. 78, 1904, p. 273.

^b Pratt, J. H., Tungsten, molybdenum, uranium, and vanadium: Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1903, p. 287.

little necessary would be rendered easy on account of the great dissimilarity between the vein material and the waste rock.

The precipitation during both summer and winter is great, and, owing to the altitude of the property, snow remains until early summer. The roads and trails from Lake Chelan to the property are generally open in June, and easy access to the mine may be had until the middle or last of September. On September 15, 1914, the company's men, who were carrying on development and assessment work, left the property for the winter, and on the next day, when the author visited the property, a heavy fall of snow took place.

If further development should disclose sufficient ore of similar character to that already in sight to warrant the installation of the necessary machinery, no difficulty should be experienced in concentrating the ore. A large part of the molybdenite could be efficiently recovered by hand picking after crushing the coarse pieces. The discard might then be reduced to perhaps 10 mesh and treated by electrostatic methods. Concentration tests of nearly similar ores lead the author to believe that a high recovery and a high-grade concentrate could be made.

MOLYBDENITE NEAR LOOMIS, OKANOGAN COUNTY.

There is a large deposit of low-grade molybdenite ore about 10 miles from Tonasket, Okanogan County, on one of the spurs of the Aeneas Mountains. It may be readily reached by automobile from Tonasket or from Loomis, both towns being about the same distance from the property. The deposit, which is owned by Andrew Starr, of Tonasket, appears to consist of a blow-out or chimney of medium-grained light-gray granite in which the molybdenite, associated with pyrite, occurs as small flakes up to an eighth of an inch in diameter. The writer would judge that the average molybdenite content of the granite was 0.5 per cent, but by careful hand picking ore containing 2 or 3 per cent of molybdenite might be obtained. At the time of the author's visit to the property in the late fall of 1914 the limits of the outcrop of the ore body had not been determined, as in most places the granite was covered with considerable soil, but so far as prospected it appeared to be about 200 by 400 feet. The principal development work consisted of two short prospect tunnels, the relative locations of which are shown in Plate XVII, *B*. The principal constituents of the granite are quartz, feldspar, and biotite. The feldspars have been considerably altered to sericite and kaolin. Accessory minerals are ilmenite, apatite, and zircon. Dr. F. B. Laney, of the United States Geological Survey, who kindly examined samples of ore from this deposit for the author, states that:

The molybdenite and a small amount of pyrite are distributed irregularly through the rock in such a manner as to suggest the possibility of their being original constit-

uents. In some places the molybdenite occurs in irregular fractures, but is by no means confined to them. Indeed it is distributed pretty well throughout the whole mass of the specimens studied, but appears to be more abundant in the more highly quartzose parts of the rock, thus possibly indicating that it is a late addition to the solidifying or partly solidified magma.

OTHER OCCURRENCES OF MOLYBDENITE IN WASHINGTON.

DEPOSIT NEAR SAFETY HARBOR CREEK, CHELAN COUNTY.

Molybdenite associated with chalcopyrite is reported to occur in Chelan County near the head of Safety Harbor Creek, which flows into Lake Chelan on its northwestern shore about 25 miles in an air line from the foot of the lake. The deposit is situated on the northwestern side of the creek, opposite the Navarre Peaks, and is at an elevation of about 6,000 feet. It is 10 miles over a good trail from the mouth of the creek to the camp. The situation of the deposit is shown in figure 1. The following notes regarding the property were kindly furnished ^a by the owner, P. Robischaud, of Lakeside, Wash. The deposit consists of two systems of veins, one running approximately east, the other north. About 700 feet of development work has been done, mostly in tunnels. The main tunnel is about 330 feet long, and 200 feet of drifts has been run from it. Twelve fissures running east and three running north have been cut. All of these are small, being 18 inches or less in width. The greatest depth reached on any of the veins is about 200 feet. The country rock is said to be porphyry.

Specimens of ore submitted to the bureau consist of a highly altered rock containing molybdenite and chalcopyrite. In most of the specimens the two minerals are not intimately associated, the molybdenite being confined to areas bounding those in which the chalcopyrite occurs; for example, in one piece showing a 4½-inch streak of chalcopyrite the molybdenite occurs in two bands about half an inch wide on either side of the chalcopyrite. The rock in which the sulphides occur has been so changed that determination of its original composition is impossible. The principal constituents are quartz, a carbonate that is seemingly siderite, and a phosphate that is probably apatite.

DEPOSIT ON SHEEP MOUNTAIN, OKANOGAN COUNTY.

J. M. Risley, of Twisp, Wash., has furnished the following information concerning a molybdenite deposit on Sheep Mountain in the northern part of Okanogan County.^b The property, which consists of five claims, is situated about 1 mile south of Monument No. 11 of the United States-Canadian boundary line and about 20 miles from

^a Letter of Nov. 21, 1914.

^b Letters of Dec. 28, 1914, and July 23, 1915.

Ashnola Siding, a station in British Columbia on the branch line of the Great Northern Railroad to Princeton. The best route to the claim is said to be over a wagon road that runs from this station up the Ashnola River for 8 miles and thence by trail about 12 miles to the property. On the Washington side the deposit is about 55 miles by trail from Twisp.

The deposit consists of three roughly parallel veins 4 to 7 feet wide, the outcrops of which may be traced almost horizontally along the side of the mountain. The veins are well defined and traverse a granite country rock. The altitude of the lowest vein is about 8,000 feet and that of the highest is about 9,000 feet. The two lower veins are below timber line, but the third is above it. Development work consists of several open cuts and short tunnels. Specimens sent to the bureau show the vein material to be a pegmatite in which the molybdenite occurs as flakes up to a quarter of an inch in diameter, associated with molybdite and pyrite. The specimens submitted were free from copper minerals and were estimated to contain about 1 per cent of molybdenite.

PROSPECTS NEAR OROVILLE, OKANOGAN COUNTY.

The author has noted the occurrence of small quantities of molybdenite associated with chalcopyrite in quartz in the Forty-ninth Parallel, Golden Chariot, and O. K. prospects, all of which are situated about 3 or 4 miles north of Oroville, Okanogan County, on the eastern slope of the hills on the west shore of Lake Osoyoos. The mineral also occurs near Concnunuly in the same county, associated with quartz, sericite, pyrrhotite, and secondary calcite.^a

MISCELLANEOUS OCCURRENCES.

Other localities in the State in which molybdenite occurs are as follows: Near Skykomish, King County, with chalcopyrite and bornite;^b in the Monte Cristo district, Snohomish County, as occasional fine flakes;^c in Pierce County on the north side of Mount Ranier near the White River Glacier at an altitude of about 5,000 feet;^d on Thunder Creek, a tributary near the head of the Skagett River;^e in Ferry County on many prospects in the Sanpoil district;^f also in the Metalline district in Stevens County.^g

^a Specimen in U. S. National Museum.

^b Specimen in Museum of California Bureau of Mines.

^c Spurr, J. E., The ore deposits of Monte Cristo, Wash.: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, 1901, pp. 777-865.

^d Letter from Milnor Roberts, University of Washington, Nov. 20, 1913.

^e Idem.

^f Sanford, Samuel, and Stone, R. W., Useful minerals of the United States: U. S. Geol. Survey Bull. 585, 1914, p. 205.

^g Sanford, Samuel, and Stone, R. W., loc. cit.

**TABULATION OF MOLYBDENITE AND OF WULFENITE OCCURRENCES
IN THE UNITED STATES.**

Following are tabulations showing molybdenite and wulfenite occurrences in the United States, with remarks and references to descriptive literature.

Occurrences of molybdenite in the United States.

State.	Remarks.	Reference.
Alaska:		
Jumbo mine, Sulzer.....	In altered limestone (?) with chalcopyrite.	U. S. Geological Survey Prof. Paper 89, 1915, p. 49.
Treadwell mine.....	Frequent in ore.....	Trans. Am. Inst. Min. Eng., vol. 35, 1905, p. 503.
Chilcoot Pass.....		Specimen in U. S. National Museum.
At mile 192 on Copper River & Northwestern R. R.		Min. and Eng. World, vol. 37, 1912, p. 582.
On Lost River, Seward Peninsula.	Fairly coarse aggregates in iron-stained siliceous gangue.	Specimens in collection of U. S. Geol. Survey.
Arizona:		
See pp. 52 to 58.....		
California:		
See pp. 58 to 63.....		
Colorado:		
See pp. 63 to 72.....		
Connecticut:		
At Haddam, Middlesex County.	In gneiss.....	Specimen in Brush collection, Yale University; and Dana, E. S., A system of mineralogy, 6th ed., 1911, p. 41.
At Saybrook.....	In pegmatite.....	Dana, E. S., loc. cit.
South Glastonbury, Hartford County.		U. S. Geol. Survey Bull. 585, 1914, p. 53.
Idaho:		
At Knob Hill, Kootenai County	On property of the Sauca Consolidated Co.	Min. Ind., vol. 16, p. 723.
Seven Devils district.....	In Chieftan Copper mine.....	Specimen in California Bureau of Mines Museum.
At Leadore, Lemhi County.....	Small flakes with sericite.....	Specimens in collection of U. S. Geol. Survey.
On south fork of Salmon River, 14 miles from Warren.		Min. Ind., 1905, vol. 14, p. 450.
Maine:		
At Cooper, Washington County.	Flakes in pegmatite dikes and granite.	U. S. Geol. Survey Bull. 340, 1908, pp. 231-240; and U. S. Geol. Survey Bull. 260, 1905, pp. 197-199.
At Brunswick, Cumberland County.	With quartz, feldspar, and biotite.	Specimen in U. S. National Museum; U. S. Geol. Survey Bull. 340, 1908, p. 236.
At Blue Hill Bay and Camdage farm, Hancock County.	In large crystals.....	Dana, E. S., loc. cit.
At Bowdoinham, Sagadahoc County, and Sanford, York County.		Do.
At Tunk Pond, Hancock County.	Flakes in pegmatite dikes and granite.	U. S. Geol. Survey Bull. 340, 1908, pp. 231-240; Min. World, vol. 31, 1909, pp. 323, 324.
At Buckfield, Oxford County.....		Eng. and Min. Jour., vol. 82, 1906, p. 1106; U. S. Geol. Survey Bull. 340, 1908, pp. 236-237.
At Greenwood, Oxford County.....		Eng. and Min. Jour., vol. 82, 1906, p. 1106.
Mount Mica, 4 miles east of Paris.	In pegmatite.....	U. S. Geol. Survey Bull. 340, 1908, p. 237.
Massachusetts:		Dana, E. S., loc. cit.
At Shutesbury, east of Locke's pond.		Do.
At Brimfield.....	With iolite.....	Letter from C. H. Warren, Boston, Mass.
At Rockport.....	In granite.....	Do.
At Quincy.....	do.....	
Minnesota:		
Near Portage, Aitkin County.....		Min. Res. U. S., 1901, U. S. Geol. Survey, 1902, p. 267.
Montana:		
See pp. 72 to 76.....		

Occurrences of molybdenite in the United States—Continued.

State.	Reimar's.	Reference.
Nevada:		
At Scott's camp, near Alpine.		Letter from G. Scott, Alpine, Nev., Nov. 9, 1914.
Lander County.....		Specimen in Nevada exhibit of Pan.-Pac. International Expo., 1915.
Near Lewis, Lander County.....		Specimen in California Bureau of Mines Museum.
In Tule Canyon, Esmeralda County.....	In quartz.....	Specimen in Nevada exhibit of Pan.-Pac. International Expo., 1915.
14 miles from Tonopah on Lone Mountain, Esmeralda County.	With powellite, scheelite, and kaolin.....	Eng. and Min. Jour., vol. 76, 1903, p. 667.
At Columbia, Esmeralda County.		Specimen in U. S. National Museum.
10 miles west of Winnemucca, on Rose Creek, Humboldt County.		Eng. and Min. Jour., vol. 87, 1909, p. 775.
Winnemucca, Humboldt County.	With quartz, chalcopyrite, and gypsum.	Specimen in U. S. National Museum.
At Mena, Mineral County.....	Fine grains with molybdenite in siliceous gangue.	Specimens in collection of U. S. Geol. Survey.
26 miles north of Golconda, Humboldt County.	Fairly large aggregates in siliceous gangue.	Do.
Near Amos, Humboldt County.	Fine flakes with quartz sericite, and pyrite.	Do.
Near Yerington, Lyon County.....	Fairly large masses with quartz and feldspar.	Do.
Near head of Death Valley.....		U. S. Geol. Survey Bull. 585, 1914, p. 120.
In Yerington district, Lyon County.	In pegmatite.....	Do.
At Redlich, Mineral County....	In quartz veins.....	Do.
At Oak Springs, 45 miles north of Johnnie Siding, Nye County.	With powellite and scheelite.....	Do.
New Hampshire:		
At Westmoreland.....	In quartz and feldspar.....	Specimens in U. S. National Museum and Brush collection, Yale University; Dana, E. S., A system of mineralogy, 6th ed., 1911, p. 41.
At Llandaff.....	In tubular crystals.....	Dana, E. S., loc. cit.
At Franconia.....	With kaolinized feldspar, muscovite, and molybdate.	Do.
Walpole.....	With feldspar and hornblende.....	Specimen in U. S. National Museum.
Warren.....		Do.
New Jersey:		
At Stanhope, Sussex County.....	In a fine-grained magnetite with massive pyrite in the Hude mine; also in Stanhope mine.	Eng. and Min. Jour., vol. 78, 1904, p. 101; U. S. Geol. Survey Bull. 585, 1914, p. 127.
McAfee.....	With augite and pyrrhotite in crystalline limestone.	Specimen in U. S. National Museum.
Hackettstown.....	With chalcopyrite and pyroxene.	Specimen in Field Museum of Natural History.
Edison, Sussex County.....	Crystals in granitoid rock in Ogden mine.	Specimen in American Museum of Natural History.
New Mexico:		
See pp. 77 to 79.		
New York:		
In New Bed mines, Essex County.	With pyrrhotite.....	Trans. Am. Inst. Min. Eng., vol. 27, 1897, p. 199.
In Port Henry iron mines, Essex County.		Do.
Natural Bridge, Jefferson County.		Specimen in California Bureau of Mines.
Lyon Mountain, Clinton County		U. S. Geol. Survey Bull. 585, 1914, p. 138.
West Point, Orange County.	With rutile, zircon, and pyrite.	Dana, E. S., A system of mineralogy, 6th ed., 1892, p. 41.
2 miles southeast of Warwick, Orange County.		Specimen in American Museum of Natural History.
New York City, near Forty-second Street and First Avenue.	In gneiss.....	Specimens in American Museum of Natural History and in Brush collection, Yale University.
Tilly Foster mine, Brewster, Putnam County.	With hornblende, augite, chlorite, pyrrhotite, and magnetite.	Specimen in U. S. National Museum.
Lake Champlain.....	With quartz, feldspar, and muscovite.	Min. Ind., vol. 6, 1897, p. 485.
Adirondack Mountains.....		

Occurrences of molybdenite in the United States—Continued.

State.	Remarks.	Reference.
North Carolina:		
Demming, McDowell County.	With quartz, muscovite-biotite schist.	Specimen in U. S. National Museum.
Near Pioneer Mills mine, Cabarrus County.	In granite and quartz.	Genth, F. A., Minerals of North Carolina, 1891, p. 23.
Near Concord, Cabarrus County.	With pyrite in quartz.	Dana, E. S., loc. cit.
Guilford County.		Hintze, Carl, <i>Handbuch der Mineralogie</i> , vol. 1, 1898, p. 417.
Allegheny County.	In Peach Bottom mine.	Do.
At Haskett's, Macon County.		Do.
West of the Blue Ridge.		Do.
Oklahoma:		
Near Roosevelt, in Wichita Mountains.		Eng. and Min. Jour., vol. 77, 1904, p. 398.
Oregon:		
Copper Creek, Eagle Mountains, Baker County.	In white quartz.	Bull. University of Oregon, vol. 1, No. 4, 1904, p. 100.
Nine miles from Huntington, down Snake River, Baker County.		Letter from J. L. McKeever, Chicago, Ill., Mar. 28, 1914.
Glacier Park, Middle Eagle Creek.		Bull. University of Oregon, vol. 1, No. 4, 1904, p. 100.
At Drum Lumraon mines, in T. 6 S., R. 44 E.	With copper minerals in center of vein 8 feet wide.	Do.
Near Galice, Josephine County.		Min. Ind., vol. 16, 1907, p. 723, and vol. 18, 1909, p. 531.
Pennsylvania:		
Frankford, Philadelphia County	In gneiss, with feldspar, quartz, and biotite; also pegmatite; from Hoffman's quarry, with granular quartz and diopside.	Specimens in Brush collection, Yale University, American Museum of Natural History, and U. S. National Museum; Trans. Am. Inst. Min. Eng., vol. 31, 1901, p. 443.
Germantown.	From stone quarries.	Proc. of the Academy of Natural Science, 1887, p. 38.
Chester, near Reading.	With feldspar, quartz, and muscovite.	Specimen in U. S. National Museum.
Morton, Delaware County.	In Johnson's quarry, with feldspar, quartz, and biotite.	Do.
Avondale, Chester County.	Leiper's quarry, with feldspar, quartz, and muscovite.	Do.
Rhode Island:		
Copper Mine Hill, Cumberland.	In serpentine matrix with malachite.	Specimen in American Museum of Natural History.
Near Sneech Pond, Cumberland.	In manganese ore.	U. S. Geol. Survey Bull. 585, 1914, p. 165.
South Carolina:		
In Haile gold mine, northeast of Kershaw, on Lynches Creek, Lancaster County.	With pyrite carrying gold.	U. S. Geol. Survey Bull. 293, 1906, p. 81.
Texas:		
South of Bluffton, Llano County.	In granite, with cyrtolite and ferugosite, with powellite.	Am. Jour. Sci., ser. 4, vol. 38, 1914, p. 485; specimen in U. S. National Museum.
Utah:		
Alta, Little Cottonwood district.	With quartz.	Specimen in U. S. National Museum.
In Peruvian Gulch, 1½ miles west of Alta, Salt Lake County.	In siliceous gangue, with pyrite.	Specimens in collection of U. S. Geol. Survey.
Near Leamington, Millard County.	Flakes in quartz.	Mineral Resources, U. S., 1901, U. S. Geol. Survey, 1902, p. 266.
Vermont:		
At Newport.	With apatite.	Dana, E. S., loc. cit.
Lexington.	With feldspar and quartz.	Specimen in U. S. National Museum.
Not given.	With kaolinated feldspar and molybdate.	Do.
Washington:		
See pp. 79 to 85.		
Wyoming:		
Albany County.	With quartz.	Field Museum of Natural History.
Encampment, Carbon County.		Specimen in California Bureau of Mines Museum.
The Illinois claim of Shoshone Mountain Mining Co., Kirwin.	Flakes in quartz.	Letter from Henry Schnitzel, Deadwood, S. Dak., Apr. 3, 1911.

Occurrences of wulfenite in the United States.

State.	Remarks.	Reference.
Arizona:		
See pp. 45 to 52.		
California:		
Potrero, San Diego County.	In quartz, with malachite and chalcopyrite.	Specimen in California Bureau of Mines Museum.
Lavis, San Bernardino County.		Specimen in Museum of Yale University.
Inyo County.	In Empire mine.	Dana, E. S., A system of mineralogy, 6th ed., 1911, p. 991.
Mount St. Helena, Napa County.	In quartz.	Specimen in California Bureau of Mines Museum.
Colorado:		
At Leadville.	In ferruginous limestone.	Specimen in Field Museum of Natural History.
Massachusetts:		
Southampton.	With quartz and sometimes with pyromorphite.	Dana, E. S., loc. cit.; specimens in Field Museum of Natural History, American Museum of Natural History, and Brush collection, Yale University.
At Loudville, in Manhan lead mines, Hampshire County.	Sometimes hemimorphic crystals.	Dana, E. S., op. cit., p. 73, and U. S. Geol. Survey Bull. 585, 1914, p. 97.
Montana:		
See pp. 76 to 77.		
New Mexico:		
See pp. 77 to 78.		
Nevada:		
Eureka District, Eureka County, in Eureka Consolidated and K. K. mines; on Ruby Hill.	With quartz, calcite, and limonite. Possibly of commercial importance.	Trans. Am. Inst. Min. Eng., vol. 6, 1877-78, p. 559; U. S. Geol. Survey Bull. 585, 1914, p. 123; specimens in Brush Collection, Yale University, U. S. National Museum, Colorado State Museum, American Museum of Natural History, and in Field Museum of Natural History. Specimen in American Museum of Natural History and Museum in California Bureau of Mines.
Tecoma, Elko County.	White calcite on limonite.	Dana, E. S., op. cit., p. 990.
On Comstock Lode, Storey County.		
Redemption mine, Esmeralda County, 1½ miles south of Hornsilver.		U. S. Geol. Survey Bull. 585, 1914, p. 123.
4 miles east of Crescent, Clark County.	With vanadinite.	Do.
Quartette mine, Searchlight, Clark County.	With cysocolla and cerussite.	Specimen in Harvard collection, Harvard University.
Eldorado mine, Belmont, Nye County.		Specimen in Brush collection, Yale University.
New York:		
Near Sing Sing.	With vanadinite and pyromorphite on crystalline limestone.	Dana, E. S., op. cit., p. 991.
Pennsylvania:		
Phoenixville, Chester County.	With granite, pyromorphite, anglesite, cerussite, quartz, and galena.	Dana, E. S., loc. cit.; specimens in Brush collection, Yale University; American Museum of Natural History, U. S. National Museum, and Field Museum of Natural History.
Perkiomen, Montgomery County.	With pyromorphite in quartz.	U. S. Geol. Survey Bull. 585, 1914, p. 164; specimens in Brush collection, Yale University, and in American Museum of Natural History.
Eaton mines, near Audubon, Montgomery County.		U. S. Geol. Survey Bull. 585, 1914, p. 164.
Pequea mines, Lancaster County.		Do.
South Dakota:		
Richmond mine, Black Hills.	With quartz, cerussite, and limonite.	Specimen in U. S. National Museum.
Utah:		
At Alta in the Continental-Alta and City Rocks mines, Little Cottonwood district, Salt Lake County.	In limestone with lead ore.	U. S. Geol. Survey Bull. 340, 1907, pp. 239-240.
Lucien district, Box Elder County.	With limestone.	Specimen in Field Museum of Natural History and Brush collection, Yale University.

Occurrences of wulfenite in the United States—Continued.

State.	Remarks.	Reference.
Utah—Continued. In Tecomah mine.....		Dana, E. S., loc. cit.; specimen in Brush collection, Yale Uni- versity.
In Harrington Hickory mine, Beaver County.		Specimen in collection of U. S. Geol. Survey.

PART III. CONCENTRATION.

IMPORTANCE OF SUCCESSFUL CONCENTRATION OF LOW-GRADE ORES.

Successful concentration of the low-grade ores of molybdenum is the one factor on which the future of molybdenum mining depends more than on anything else. Outside of a small and irregular production of wulfenite concentrates, the molybdenum markets of the world have to date been supplied largely by a molybdenite product containing 50 to 90 per cent MoS₂, obtained by the primitive process of cobbing and hand picking high-grade ore. In a few instances hand picking has been supplemented by coarse crushing, preferably in rolls or some similar type of machine that tends to flatten the crystals or flakes of molybdenite, followed by screening to separate the coarser particles of molybdenite from the gangue. That such a method is extremely wasteful is self-evident, and probably in every instance where it has been employed more molybdenite has been thrown on the dump as waste than has been saved. But aside from the inefficiency of the process, the known supply of rich ore on which it can be applied with success, even at the present high price of the molybdenite product, is so small as to promise a yield of only a few tons. Barring the discovery of extensive high-grade deposits of molybdenite, the product obtained by cobbing, hand picking, and screening out the coarser flakes of the mineral will not yield a hundredth part of the tonnage of concentrates requisite to the proper development of the market. Neither will the few known commercial deposits of wulfenite, which is easily concentrated, be able to supply the demand. Low-grade molybdenite ores, of which there are large deposits containing 1 to 3 per cent MoS₂, must therefore be treated.

As yet it has not been proven that any of the chemical or metallurgical processes so far used or proposed for extracting molybdenum are nearly as economical as mechanical processes of concentration when directly applied to low-grade molybdenite ores, particularly if the deposits are situated at a distance from railroad transportation. It appears, therefore, that the mechanical concentration of such ores, including a study of methods for the removal of deleterious elements, such as copper, from the concentrates is the chief problem to be considered. The Bureau of Mines hopes by investigation of these questions to obtain results that will point the way to the establishment of a successful industry.

In this report the question is necessarily taken up in a preliminary way as the bureau has at present no equipment of its own for conducting concentration tests. However, a discussion of the more successful existing methods of concentration is attempted here, and is supplemented by the results of a number of concentration tests of ores selected as representative of typical deposits. The tests described were made possible through the kindness of various companies and individuals who placed the equipment of their testing laboratories at the author's disposal. These tests were of necessity made on laboratory-size machines and on small lots of ore, and the results must be considered only as indicative of what may be expected from the treatment of commercial quantities of ore on machines of standard size.

With proper equipment at its command the bureau hopes to develop improved processes of concentration of these low-grade ores, the results of its work to appear in a succeeding report.

Of the two commercial ores of molybdenum, namely, molybdenite and wulfenite ores, the first are not amenable to the ordinary processes of concentration by jigs, tables, vanners, slimers, etc., such as are usually employed in treating ores of copper, lead, zinc, gold, and silver, as the grains or flakes of molybdenite even when of considerable size float readily on water and therefore are lost if these methods are employed. On the other hand, little difficulty is experienced in the adaptation of the ordinary jig and table processes to wulfenite ores, as they are readily wetted, and because of the high specific gravity (6.7 to 7) of wulfenite it is much heavier than any of the gangue-forming constituents of most of its ores. On account of the wide difference in the character of molybdenite and of wulfenite ores and the necessity of subjecting them to entirely different processes of treatment, the concentration of each is considered separately.

CONCENTRATION OF MOLYBDENITE ORES.

Until recently, practically all the processes of concentration of molybdenite that have been attempted on a commercial scale in the United States have been unqualified failures. A number of companies have erected mills and installed various rolling and screening processes, pneumatic separators, and wet concentrators similar to or adaptations of those usually employed in the treatment of lead, zinc, and copper ores. These mills have operated only a few weeks at the most, and, as far as the author knows, only one company produced more than a ton of marketable concentrates. In several instances, the processes were absolutely unsuited to the ores to which they were applied, and their unsuitability could have been conclusively shown by a trial on an experimental scale. In other instances processes that

seemed to promise success from small-scale tests were failures on a commercial scale owing to difficulties in their practical application.

Notwithstanding this record of continuous failures, and although the concentration of molybdenite ore has been considered one of the most difficult problems in ore dressing, there are methods of treatment that have been developed for some time that can be applied to many molybdenite ores with certainty of success. Before proceeding to describe these processes it may be well to state that there is no method suitable for the treatment of molybdenite ores in general, but that each particular ore usually involves its own individual concentration problems; a method or combination of methods that might give highly satisfactory results with one ore might prove an unqualified failure with another. In describing each process the author will attempt to show to which particular type of ores it is adapted, and how some ores are best treated by a combination of processes.

Methods of concentration that have been used with success with molybdenite ores may be grouped under three general heads, as follows: (1) Rolling and screening processes; (2) electrostatic methods; (3) flotation processes. Each of these is considered separately.

ROLLING AND SCREENING PROCESSES.

A considerable proportion of the molybdenite in some ores in which the mineral occurs as large flakes or crystal aggregates may be recovered by crushing the ore in rolls and then screening the crushed material. The success of the process depends entirely upon flattening the molybdenite masses into flakes the maximum diameters of which are in excess of those of the particles of gangue material. Usually before the ore is screened it is passed through a series of rolls to break the gangue into small particles. The material passing through the first screen is again crushed in rolls and screened, and the process repeated as many times as may appear to be advantageous.

About 10 years ago the American Molybdenum Co., of Boston, erected a mill at Cooper, Me., for the recovery of molybdenite by the process outlined above. Hess^a comments on this plant as follows:

The plant consisted of a 35-horsepower boiler and engine, a Sturtevant jaw crusher and roll, and four sets of special rolls, each 3 feet in diameter and 10 inches wide. The crusher was but a couple of feet above the floor, from which the material, crushed to about one-fourth inch square, was elevated to the Sturtevant roll, 18 inches in diameter by 4 inches wide, which reduced the ore to about one-eighth inch. It was then elevated to a bin at the top of the building, from which it fell to a series of two special rolls, thence was elevated to a third special roll, and run through a 34-mesh screen. The molybdenite caught on the screen was delivered to a box at the end. The material going through the screen was carried by an elevator and screw conveyor to a fourth roll, from which it fell onto a 40-mesh screen and from that to a 60-mesh screen. What

^a Hess, F. L., Some molybdenum deposits of Maine, Utah, and California: U. S. Geol. Survey Bull. 340, 1907, p. 233.

went through the 60-mesh screen was elevated and sent to the tailings pile. It is readily seen that the repeated elevations of the material meant a considerable waste of power. The mill ran only six weeks, and is said to have made about a ton of concentrates, a portion of which seen by the writer was very clean. In the tailings some fine flakes of molybdenite were found, but the amount seemed small. Such a process, if mechanically perfected, might work profitably on deposits where, as in this one, the molybdenite flakes are comparatively broad, but would be wholly unsuited to deposits like many of those in Colorado and elsewhere, in which the individual flakes are of almost microscopic size.

Modifications of the rolling and screening process have been employed at other molybdenite mines both in this country and in Australia. All of them have proved inefficient, and in most instances where they have been used as the sole method of recovery more of the mineral has been thrown on the waste dump than has been saved. In the author's opinion, rolling and screening are of value only as preliminary treatment to remove the coarser and heavier masses of molybdenite from ores in which the mineral occurs in fairly large aggregates. The application of such treatment to this type of ore may be desirable in a few instances, as it saves a considerable part of the molybdenite in coarse form, thereby doing away with losses that would inevitably occur if the large pieces were broken up. How far rolling and screening should be continued depends, of course, on the nature of the ore and on what process of treatment is to follow. In general, however, screening to recover a concentrate should not proceed beyond the point where the succeeding process will begin to handle the material efficiently. Ores containing mica are of course unsuited to this method.

ELECTROSTATIC PROCESSES.

PRINCIPLES OF SEPARATION.

Molybdenite, in common with many other minerals, such as chalcopyrite, pyrite, pyrrhotite, and galena, is a good conductor of electricity as compared with quartz, feldspar, and most other silicates, calcite, etc., which are poor conductors. Hence it may be separated from a majority of the gangue minerals with which it occurs by electrostatic processes. The principle on which these processes are based is that two bodies charged with electricity of similar sign repel each other, but when charged with electricity of opposite signs they attract each other. When minerals that are good conductors of electricity come in contact with a charged body or an electrical field, they almost instantly attain an electrical equilibrium with that body or field and are repelled, whereas as regards poor conductors the time necessary for equilibrium to be reached is so appreciable that if the contact is of short duration the repelling force is negligible. Further, if the mixture of two minerals that are good and poor con-

ductors—for example, molybdenite and quartz—is charged to a high potential with electricity of one sign and placed in contact with a body charged with electricity of opposite sign, the mineral that is a good conductor (molybdenite) almost instantly assumes the charge of the body with which it is in contact, and is repelled. On the other hand, the mineral that is a poor conductor (quartz) is only slowly affected and retains its own charge of opposite sign for an appreciable length of time, and in consequence is attracted to the body with which it is in contact.

RANGE OF APPLICATION.

Theoretically a separation can be effected between any two minerals that differ in degree of conductivity, regardless of whether they are good or poor conductors, but in commercial work it has been impossible to make a separation of good conductors, as there is practically no difference in the time required for them to reach an electrical equilibrium. Therefore, although molybdenite may be separated from quartz, limestone, porphyry, granite, etc., it can not be separated electrostatically from chalcopyrite, pyrite, pyrrhotite, etc. The table following lists the more common minerals and rocks with which molybdenite occurs and shows whether they are good or poor conductors of electricity. In other words, the table indicates whether the mineral mentioned can or can not be separated from molybdenite by electrostatic means. However, it does this in only a general way, as many minerals of varying composition, such as garnet and sphalerite, are sometimes conductors and sometimes nonconductors. Accordingly it is unsafe to predict just what separations may be effected, and the suitability of electrostatic processes for the treatment of any molybdenite ore can be positively ascertained only by actual tests.

Minerals and rocks associated with molybdenite, showing whether they are good or poor conductors of electricity.

Good conductors.	Poor conductors.
Chalcopyrite.	Quartz.
Bornite.	Feldspar.
Chalcocite.	Granite.
Most other copper minerals.	Quartzite.
Pyrite.	Porphyry.
Pyrrhotite.	Garnet. ^a
Magnetite.	Most silicates.
Most other iron minerals.	Calcite.
Galena.	Limestone.
Hornblende.	Sphalerite. ^a
Garnet. ^a	
Sphalerite. ^a	

^a Some varieties are good conductors; others are poor conductors.

For the successful application of electrostatic methods to the concentration of molybdenite the ore must be one in which the individual particles of molybdenite are of fair size and in which the gangue and other principal associated minerals are nonconductors. Ores in which the molybdenite is extremely fine to almost amorphous requires fine crushing to free the individual grains from the gangue. Such crushing is not desirable, as it makes dust that usually interferes with the separation and also lowers the capacity of the separators. Thus, the best results are obtained from the treatment of coarse material, so that the ores that are best suited for electrostatic separation are those in which the particles of molybdenite are flaky and of good size, and in which the gangue is clean quartz, granite, etc.

The main requisite in the treatment of the ore is that it be perfectly dry and warm. The necessity of removing all moisture can not be emphasized too strongly, as its presence, even in small quantities, in quartz, feldspar, etc., make these minerals conductors. Ore as coarse as 6-mesh and as fine as 200-mesh may be treated successfully, but, as already stated, the best results are usually obtained with coarse material. Close sizing of the ore is generally unnecessary, but it is apt to improve results, especially in the treatment of coarse material. Dust in the ore should be removed by a blower or other device before the ore is treated.

DESCRIPTION OF SEPARATORS.

The electrostatic separators used in this country are of two main types. One of them consists essentially of a series of metal rods or electrodes charged to a high potential and placed one above the other in an insulated frame. On the top of this frame is a hopper from which the ore is fed by a revolving roll. The ore falls from the roll against the first electrode, and good conductors that come in contact with it are repelled. The residue is thrown against the second electrode by means of a deflector, and more mineral particles that are good conductors are thrown out. The operation is repeated any number of times desired simply by increasing the number of charged rods or electrodes. Generally a standard separating unit of this type consists of a "rouger" and two "cleaners," each having six electrodes. The cleaners are placed back to back and the rouger is placed above them in such a manner that the concentrates from the rouger fall against the first electrode of one cleaner, and the tailings against the first electrode of the other cleaner. In this way the rough concentrates and tailings are re-treated separately. With the exception of the feed roll there is no moving part in the unit, and, consequently, its operation is extremely simple, and the cost of upkeep negligible. High-voltage electricity for charging the electrodes is supplied by stepping up current of ordinary voltage by

means of a rotary transformer. Thus the operation of the separator is independent of weather conditions, which so noticeably affect the operation of electrostatic generators.

The other type of separator has a revolving metal electrode onto which ore is fed. Opposite and adjacent to it is another electrode consisting of a row of sharp metal points. The first electrode is grounded, and the second is connected to one pole of an electrostatic generator, the other pole of which is grounded. The electricity delivered to the pointed electrode is discharged by convection to the grounded electrode and is dissipated as fast as received. The revolution of the grounded electrode carries the mineral particles through the convective discharge and results in their receiving a charge. Good conductors immediately lose this charge to the grounded electrode on which they rest; consequently they are neither attracted nor repelled by the electrode but simply fall off of it as it revolves. On the other hand, mineral particles that are poor conductors accumulate a charge on their surfaces nearest the pointed electrode, and on account of their nonconducting character they are polarized and are caused to adhere to the revolving electrode. These particles are brushed off the back of the electrode by a felt roller.

Three of the separating units described above are generally combined in one machine for commercial work in such a manner as to provide for three successive treatments of the mineral particles that are good conductors. In the separation of molybdenite and quartz, for example, a rough concentrate would be made on the first unit and it would be further cleaned on the second and third units.

This type of separator is open to the objection that it is dependent on electrostatic generators for its supply of electricity, and in moist climates or wet weather these give much trouble in their operation.

CONCENTRATION TESTS.

The tests described below were made on molybdenite ore submitted by the Santa Maria Molybdenum Mining & Milling Co., of San Diego, Cal. The ore, which was said to be a representative sample from this company's property 40 miles east of that city, was an iron-stained granite containing about 0.5 per cent of molybdenite and a small quantity of pyrite. The molybdenite occurred in radiating masses from the size of a pea to an inch or more in diameter. Microscopic examination showed that the granite was composed of quartz, orthoclase, plagioclase varying from albite to oligoclase, biotite, and a few minor accessory minerals. This ore was selected for these tests as in a general way it was typical of ores from a large number of deposits.

On account of the low grade of the ore it would be necessary to hand pick it in a commercial operation, and therefore, previous to crushing for electrostatic separation, a hand-picking test was made of the sample submitted. The results of this test are given in the following table:

Results of hand picking molybdenite ore from the Santa Maria Molybdenum Mining & Milling Co.'s property, 40 miles east of San Diego, Cal.

Item.	Original ore.	Sorted ore.	Reject.
Weight, pounds.....	313.62	115.62	198.00
Per cent MoS ₂	^a 47+	1.15	.08
Weight MoS ₂ , pounds.....	1.488	1.330	.158
Extraction MoS ₂ , per cent.....		.89.38	
Loss MoS ₂ , per cent.....			10.62

^a Calculated.

The lot of ore, which weighed approximately 313 pounds, was cobbled down to pieces 2 inches in maximum diameter, and hand picked. One hundred and ninety-eight pounds of the material was discarded and the remaining 115 pounds of selected ore was crushed in a laboratory-size jaw crusher to pass a 10-mesh screen. The discarded ore was also crushed through a 10-mesh screen, and both products were sampled and assayed. They contained 1.15 and 0.08 per cent MoS₂. The ratio of concentration obtained was approximately 1 to 3, and the loss of molybdenite in the discarded material about 10 per cent.

For the electrostatic tests the hand-picked ore, which had been crushed through a 10-mesh screen, was screened into three sizes—through 10-mesh on 20-mesh, through 20-mesh on 60-mesh, and through 60-mesh. The coarser size was treated on a Sutton, Steele & Steele type of concentrator and the two finer sizes on a concentrator of the Huff type. The results of these tests are given in the following table:

Results of electrostatic-concentration tests of hand-picked molybdenite ore from the Santa Maria Molybdenum Mining & Milling Co.'s property, 40 miles east of San Diego, Cal.

THROUGH 10-MESH ON 20-MESH SUTTON, STEELE & STEELE TYPE CONCENTRATOR.

Item.	Ore.	Concen- trates.	Middlings.	Tailings.
Weight, pounds.....	30.35	0.48		29.87
Per cent MoS ₂	^a 1.58	87.17		.21
Weight MoS ₂ , pounds.....	.481	.418		.063
Extraction MoS ₂ , per cent.....		86.90		
Loss MoS ₂ , per cent.....				13.10

^a Calculated.

Results of electrostatic-concentration tests of hand-picked molybdenite ore from the Santa Maria Molybdenum Mining & Milling Co.'s property, 40 miles east of San Diego, Cal.—Continued.

THROUGH 20-MESH ON 60-MESH HUFF TYPE CONCENTRATOR.

Item.	Ore.	Concen-	Middlings.	Tailings.
Weight, pounds.....	41.49	0.52	0.10	40.87
Per cent MoS ₂	^a 1.26+	76.66	41.87	.20
Weight MoS ₂ , pounds.....	.523	.399	.042	.082
Extraction MoS ₂ , per cent.....		76.29	8.03	
Loss MoS ₂ , per cent.....				15.68

THROUGH 60-MESH HUFF TYPE CONCENTRATOR.

Weight, pounds.....	37.18	0.36	0.45	36.37
Per cent MoS ₂	^a .94+	46.78	23.63	.21
Weight MoS ₂ , pounds.....	.350	.168	.106	.076
Extraction MoS ₂ , per cent.....		48.00	30.29	
Loss MoS ₂ , per cent.....				21.71

SUMMARY.

Total weight, pounds.....	109.02	1.36	0.55	107.11
Total weight MoS ₂ , pounds.....	1.354	.985	.148	.221
Per cent MoS ₂	^a 1.24+	^a 72.42+	^a 26.90+	^a .20+
Extraction MoS ₂ , per cent.....		72.75	10.93	
Loss MoS ₂ , per cent.....				16.32

^a Calculated.

It will be noted that with the coarser material a concentrate containing 87.17 per cent MoS₂ was made, and that the recovery in these concentrates was 86.9 per cent. The concentrates from the next size contained 76.66 per cent MoS₂, and accounted for 76.29 per cent of the molybdenite in the feed. However, a middling product containing 41.87 per cent MoS₂ was made, which increased the total extraction on this size of material to 84.32 per cent. The fine ore yielded concentrates and middlings that assayed 46.78 per cent and 23.63 per cent MoS₂, and accounted for an extraction of 78.29 per cent. It will be noted that the best work was done on the coarse material, both as regards recovery and grade of concentrates.

A summation of the three tests shows that the average grade of the products made was as follows: Concentrates, 72.42 per cent; middlings, 26.9 per cent; and tailings, 0.20 per cent MoS₂. The total recovery on the concentrates and middlings was 83.68 per cent. The results obtained were satisfactory when it is considered that the ore treated contained pyrite, which of necessity was concentrated with the molybdenite.

SUGGESTED METHOD FOR TREATMENT OF A TYPICAL ORE.

For ores of the same general type as that mentioned above—that is, ores in which the individual particles of molybdenite are flaky and of fair size and the gangue is clean quartz, granite, or other non-

conductor—the following general outline of the proper method of treatment is suggested:

The original ore, or selected ore, if hand picking is advisable, should be crushed in a jaw or gyratory crusher to about one-half inch to 1-inch size and the product crushed in rolls to pass a 6-mesh screen. This material should then be treated in a direct-heat rotary drier until all moisture has been removed, and screened to sizes approximately as follows: Through 6-mesh on 12-mesh; through 12-mesh on 20-mesh; through 20-mesh on 40 or 60 mesh; through 40 or 60 mesh. If much dust is present in the finest size of material, its removal with some sort of blower or other device previous to electrostatic treatment will probably be advantageous. Each size of the dried material should be treated separately on whatever type of electrostatic concentrator has been selected. The best method of operating these separators depends, of course, on their type, and also on the character of the ore being treated. In the author's opinion it is generally advantageous to operate the concentrators so as to obtain as clean tailings as possible. In this way the bulk of the material is eliminated at once, and the re-treatment of the concentrates and of the middling product takes much less time than that required in re-treating the original tailings. This method of operation will generally yield a better grade of concentrates and a higher recovery than any other. Also, the grading of the concentrates and middlings so as to obtain the best prices for the combined products can be more readily accomplished by this method. In some instances the middling products from the treatment of the coarser sizes of ore consist largely of particles of gangue with included grains of molybdenite. Under such conditions, the middlings should be crushed, sized, and re-treated.

To the author's knowledge, there are no plants that are treating molybdenite ore commercially by electrostatic methods; hence, figures as to costs of operation are unavailable. It seems reasonable to infer, however, that they would be only slightly different from those for treating zinc or other ores to which electrostatic methods have been successfully applied. The costs of drying and separating zinc-iron concentrates by electrostatic methods, including only operating costs, do not usually exceed \$1 per ton of material treated; and the total costs, including operation, royalty, taxes, and all other overhead expenses, such as interest on investment and amortization charges, usually range from \$2.50 to \$3.50 per ton. The costs of treating molybdenite ore would probably be slightly in excess of these figures, as the capacity of the separators would, no doubt, be less than when operating on zinc-iron concentrates, where the weight of concentrates and tailings produced is more nearly equal than it would be with the usual molybdenite ores. Drying of the molybdenite ore would probably cost 10 to 20 cents per ton, depending on

the size and type of drier used, the cost of fuel and labor, and the percentage of moisture in the ore.

If the electrostatic separators were so arranged that the products could be taken care of automatically, one man could tend 8 to 10 concentrators. The other labor required for operating a mill capable of treating 50 tons of crude ore per day would probably not exceed four or five men per shift, and no high-priced labor would need to be employed on account of the simplicity of the process.

The author is confident that electrostatic processes will yield good results with all molybdenite ores to which they are suited and to which they are intelligently applied, and they are of particular value for treating ore that can not be treated by flotation methods on account of the absence of requisite water supplies.

FLOTATION PROCESSES.

Molybdenite has the property, common in varying degree to most metallic sulphides, such as chalcopyrite, sphalerite, galena, pyrite, and pyrrhotite, of not being wetted readily by water, and, when dry and in small particles, of floating on a water surface. Moreover, like those sulphides, it is easily wetted by most oils. Further, in a pulp of crushed ore and water, oils have a preferential wetting action for particles of molybdenite as against particles of gangue minerals such as quartz, and this selective wetting action is decidedly increased if the water is slightly acidified. Particles of molybdenite so wetted with oil are covered with a buoyant water-repelling coating that materially assists their flotation. As the reasons for many of these phenomena—for example, the selective wetting action of oils and the increase of this selective action by acids—are not clearly understood, and as even an elementary discussion of the accepted theories of mineral flotation would be out of place here, the reader who wishes further information on the subject is referred to a clear and concise exposition by Hoover^a and to an excellent paper by Mickle.^b It suffices here to say that the phenomena mentioned above are the basis on which all flotation processes depend. In many processes the area of the effective surface of flotation is increased by the liberation of bubbles of gas or air in the liquid, the surface of each bubble acting in the same way as the horizontal surface of a liquid at rest. These bubbles may be of air and may be produced by violent agitation of the pulp or by release of air from solution in the liquid by a reduction of pressure, or they may be of carbonic-acid gas formed by the action of sulphuric acid on limestone or other carbonates or by other means.

^a Hoover, T. J., Concentrating ores by flotation, 1912, 221 pp.

^b Mickle, K. A., Flotation of minerals: Proc. Royal Soc. Victoria, vol. 23, pt. 2, 1911, pp. 555-585, abstracted by Eng. and Min. Jour., vol. 92, 1911, pp. 307-310, and vol. 94, 1912, pp. 71-76.

WATER-FLOTATION PROCESSES.

CHARACTER OF WATER FLOTATION.

Water flotation for the concentration of molybdenite depends solely on the fact that small dry particles of the mineral float readily on water, whereas the usual gangue material is easily wetted and sinks. They do not of necessity involve the use of oil, acid, or gas, and their application is extremely simple. The concentrators, which are of various types, consist essentially of a device for feeding the crushed ore in as thin a sheet and at as uniform a rate as possible onto a moving water surface in a tank and an arrangement, either by an overflow or a revolving belt of canvas or other suitable material, for discharging the floating film of concentrates into another tank. The tailings are usually drawn off from a spigot in the bottom of the first tank. In some types of apparatus the ore from the feeder is allowed to slide down an inclined plane or concave, over which a film of water is passed and from which the ore is discharged approximately in the plane of the water surface in the tank. In other apparatus the ore from the feeder falls on top of an almost submerged corrugated or canvas roller, the revolution of which carries the ore forward to the flotation surface. The object of all these devices is to place the ore on the water in a sheet only one mineral particle in depth with as little disturbance of the water surface as possible and with the majority of the particles of gangue already wetted.

Even with the best of feeding devices some particles of gangue fall on the floating film of concentrates or are otherwise mechanically entrained by it. Various methods of cleaning the film, such as allowing it to flow down an incline into a second tank, picking it up on a roller or belt and again discharging it to a flotation surface and dividing it into a large number of parts and agitating it by causing it to flow through the teeth of a comblike obstruction, are used.

No description of any particular water-flotation concentrator is attempted here, as detailed information both as to the design and the operation of a number of different types of machines is given in the references cited below.^a

NECESSARY FACTORS IN SUCCESSFUL WATER FLOTATION.

To be concentrated successfully by water flotation, a molybdenite ore should be such as to require only medium-fine crushing to liberate the molybdenite, and the gangue should be one in which the individual particles are readily wetted. Further, if a high-grade concentrate is to be obtained the ore must be practically free from other sulphides

^a Wood, H. E., The Wood flotation process: Trans. Am. Inst. Min. Eng., vol. 44, 1912, pp. 684-701; Concentration of molybdenite ores: Eng. and Min. Jour., vol. 93, 1912, pp. 227-228.

such as pyrite, pyrrhotite, and chalcopyrite, which would be concentrated with the molybdenite. Proper treatment of the ore previous to flotation is of great importance. It should be reduced to approximately 10-mesh, or as much finer as may be necessary to liberate the mineral from the gangue, by crushing in rolls in such a manner as to make the quantity of fines as small as possible. Then if it is at all damp it should be thoroughly dried. Mechanical difficulties in the proper feeding of fine ore, and the great reduction in the capacity of the concentrators when fine material is treated exclusively, render advantageous in most instances the treating of the ore without sizing, although the capacity of the concentrators and the grade of concentrates made are considerably increased when coarse material that has been sized is treated.

The capacity of water-flotation machines varies with their type and with the character of the ore treated, and depends directly on the size to which the ore is crushed, the amount of fines made, the nature of the gangue, and the ratio of concentrates to tailings. In speaking of a particular type of concentrator, Wood ^a says:

A standard machine treating a 20-mesh quartz ore, using a 3-foot width of feed and having a 4-foot take-off belt, will vary in capacity from 1,000 to 2,000 pounds per hour, unless the ratio of concentration is low, in which case the capacity will be smaller. Some ores that possess an easily wetted gangue and call for a high concentration ratio can be fed rapidly at 20-mesh, 30-mesh, or 40-mesh. For instance, a 1 or 2 per cent molybdenite ore in a quartz gangue will give a clean concentrate, even if the ore is fed several times faster than an ordinary sulphide ore.

The writer thinks that the capacities stated above could be had only at a sacrifice of either the recovery or the grade of concentrates obtained, and that a machine with a feed 3 feet wide, handling 300 to 500 pounds per hour of ore crushed to pass a 20-mesh screen would be treating about the maximum quantity of material that it could separate efficiently. No figures as to cost of operation can be given, but they are presumably small as the concentrators require only moderate quantities of water and little power.

RESULTS OF TESTS WITH WOOD'S PROCESS.

The accompanying table shows the results obtained by Wood in 10 concentration tests of five different molybdenite ores. In every test except the last, in which the ore had been slightly roasted, the recoveries were good, averaging nearly 90 per cent. In general, however, the grade of concentrates was low to medium, averaging less than 60 per cent MoS₂. Test No. 3 is of special interest as it shows the results obtained by flotation of the same ore on water at different temperatures. The decided improvement in the grade of

^a Wood, H. E., The Wood flotation process: Trans. Am. Inst. Min. Eng., vol. 44, 1912, p. 593.

concentrates by using warm water may be attributed to the decreased surface tension of the liquid allowing some particles of gangue to sink more readily. The recovery with warm water is, however, remarkable and can be accounted for only by some factor, such as a difference in the rate of feed, that would make the tests not strictly comparable. Detailed information as to the tests is given by Wood.^a A summary of the data obtained by Wood is given in a table which is presented below:

Results of concentration tests of molybdenite ores by Wood flotation process.

Test No.	Size of feed.	Per cent MoS ₂ .		Recovery, per cent.	Remarks.
		In feed.	In concentrates.		
1	Through 40-mesh..	2.08	41.38	99.00	Colorado ore. Retreatment would materially increase the grade of concentrates with little loss.
2	Through 20-mesh..	2.00	61.55	92.27	Alaskan ore.
3	.....	1.87	45.31 (a) 56.70 (b)	79.08 (a) 89.17 (b)	Canadian ore with a quartz and mica gangue. (a) was obtained with water at 56° F. and (b) with water at 110° F.
4	Through 20-mesh..	6.66	63.50	96.34	Foreign ore.
	Through 30-mesh..	6.73	67.42	86.26	
	Through 40-mesh..	6.66	65.50	86.48	
5	Through 40-mesh..	8.95	74.60	94.19	Alaskan ore containing pyrrhotite and magnetite, and low in silica. (a) was obtained with raw ore, and (b) with slightly roasted ore.
	Through 40-mesh..	8.65	30.00 (a) 81.45 (b)	79.00 (a) 26.30 (b)	

In order to obtain data as to concentration of a molybdenite ore containing copper sulphides by this process a small-scale test was made of a sample of ore from the Whale claim, in Copper Canyon, near Copperville, Ariz. The ore consisted of a clean white quartz containing about 7 per cent of molybdenite and 2 per cent of copper, present largely as chalcopyrite.^b

After the ore had been dried and then crushed in a ball mill to pass a 40-mesh screen, it was concentrated on a laboratory-size flotation machine of the Wood type. The concentrator was so arranged that the floating film of concentrates picked up by the take-off belt was discharged to a second flotation surface from which it was allowed to run into a concentrate tank. The material that sank in the second flotation tank was considered middlings. The ore and water feeds to the machine were adjusted with the idea of causing as much chalcopyrite as possible to sink. The results of the test are given in the accompanying table.

^a Wood, H. E., The Wood flotation process: Trans. Am. Inst. Min. Eng., vol. 44, 1912, pp. 684-701.

^b For a detailed description of this ore see p. 52.

Results of water-flotation test with concentrator of the Wood type of molybdenite-chalcopyrite ore from the Whale claim, near Copperville, Ariz.

Item.	Ore.	Concen- trates.	Middlings.	Tailings.
Weight, grams.....	4,000.00	538.00	107.00	^a 3,355.00
Per cent MoS ₂	b 7.10+	47.44	6.74	.65
Per cent Cu.....	b 1.93+	5.26	5.90	1.27
Weight MoS ₂ , grams.....	284.25	255.23	7.21	21.81
Weight Cu, grams.....	77.22	28.30	6.31	42.61
Extraction MoS ₂ , per cent.....		89.79	2.54	
Extraction Cu, per cent.....		36.65	8.17	
Loss MoS ₂ , per cent.....				7.67
Loss Cu, per cent.....				55.18

^a 467 grams of material lost in the overflow was assumed to assay the same as the 2,888 grams of tailings recovered.

^b Calculated.

The great difference between the percentage of recovery of molybdenite and of chalcopyrite is of particular interest. As compared with the feed, the concentrates contained approximately seven times the percentage of MoS₂ and less than three times the percentage of copper, and the recovery in the concentrates was 89.79 per cent of the molybdenite, as compared with only 36.65 per cent of the copper. Inasmuch as the crushed ore had stood only a short time before treatment, so that the particles of chalcopyrite had little opportunity to oxidize, which would cause them to be more readily wetted, the author considers the widely different results obtained in the concentration of the two minerals to be remarkable.

It is of interest to note that a water-flotation process for the concentration of molybdenite ore is being used at present on a commercial scale by Henry E. Wood & Co., of Denver, Colo.

Methods of treating both the original ore and the concentrates to remove pyrite, chalcopyrite, pyrrhotite, and other metallic sulphides and such ingredients as mica that are likely to float with the molybdenite are discussed later.

OIL-FLOTATION PROCESSES.

Many of the principal processes of concentration by oil flotation are described in detail by Hoover^a and in numerous articles that have recently appeared in the mining press. Published data giving the results obtained by the application of these processes to molybdenite ores are extremely meager, and are practically confined to the results of treatment by the Elmore vacuum flotation system. As the Bureau of Mines at present has no equipment at its disposal for conducting tests of the various flotation processes, the concentration of molybdenite by these methods must, of necessity, be discussed here in only a general way.

^a Hoover, T. J., Concentrating ores by flotation, 1912, 221 pp.

Broadly speaking, oil flotation probably offers the best method of treating molybdenite ores in general, and those particular processes that have been successfully applied in concentrating ores of the other metallic sulphides would, without doubt, meet with equal success in the treatment of molybdenite. The above statement does not mean that all molybdenite ores can be successfully concentrated by oil flotation, for the physical characteristics and mineralogical composition of an ore are as important factors in determining the success of any oil-flotation process as of electrostatic or water-flotation methods. The ores best suited for treatment by oil flotation are those in which the molybdenite is flaky. From ores in which the mineral is so fine as to be almost amorphous and the gangue contains a considerable proportion of soft material, such as kaolinized feldspar, it is almost impossible to obtain a good grade of concentrates because of the flotation of some of the finer particles of gangue. Of course, if molybdenite is associated with other metallic sulphides, such as chalcopyrite, pyrite, or pyrrhotite, these are concentrated too, and must either be removed from the ore, by a preliminary treatment, or from the concentrate if a high-grade product is desired. Methods that may be employed for this purpose are discussed later. Ores containing magnetite, hematite, garnet, hornblende, or similar gangue minerals that are good conductors of electricity, and therefore are not adapted for concentration by electrostatic methods, are especially suited for treatment by flotation.

Laboratory experiments indicate that in general the particles of molybdenite that can be floated are much coarser than those of other metallic sulphides, and if finer crushing is not necessary for the liberation of the molybdenite from the gangue, material as coarse as 20 mesh may be successfully concentrated. On the other hand, there is every reason to believe that a good recovery and a fair grade of concentrates can be obtained from the treatment of molybdenite through 200 mesh because galena and sphalerite of similar fineness have been successfully treated by oil flotation. In general, therefore, oil-flotation processes are applicable to a wider range of sizes than are electrostatic or water-flotation methods, and many of them have the added advantage of large capacities from small units. For example, Hoover estimates that in one type of apparatus used in the minerals-separation process a unit consisting of six mixing boxes each only 16 inches wide and 36 inches deep will have a daily capacity of 50 to 60 tons of ore,^a presumably Broken Hill lead-zinc tailings, and a 5-foot Elmore machine will ordinarily treat from 25 to 45 tons of crude ore in 24 hours.^b Capacities equal to and perhaps even greater than these could probably be obtained in the treatment of molybdenite ores by the same units, but no definite data either as to capaci-

^a Hoover, T. J., Concentrating ores by flotation, 1912, p. 120.

^b Hoover, T. J., op. cit., p. 101.

ties or as to costs of any oil-flotation process when applied to molybdenite ore have, to the author's knowledge, been made public. In fact, owing to the policy of secrecy adopted by most companies interested in the development of oil-flotation methods, little information is available regarding the economics of the various processes, even as more commonly applied to the concentration of the sulphides of copper, lead, and zinc. However, comprehensive data with regard to the costs of treating Broken Hill lead-zinc tailings by four well-known processes, namely, the Potter-Delprat, De Bavay, Elmore, and minerals separation, are given by Hoover.^a His estimates of 3s. 6d. (\$0.85) per ton as the average cost of flotation and 9s. 3d. (\$2.25) per ton as the average total cost of re-treating these tailings on a large scale form a poor basis on which to estimate the cost of treating molybdenite ores by the same processes in small plants such as might be installed at mines producing 50 or 100 tons of ore a day. It is safe to say, however, that the costs of small-scale concentration of molybdenite ores would be considerably higher than those given above.

RESULTS WITH ELMORE VACUUM FLOTATION.

The following table shows the results obtained in concentration tests of two molybdenite ores by the Elmore vacuum-flootation system. It will be noted that in the first test, in which the gangue was largely feldspar, the percentage recovery was high and the concentrate obtained was only medium grade, probably because of the flotation of some of the finer particles of light feldspar. In the second test, in which the gangue was relatively heavy, chiefly magnetite and garnet, both the grade of concentrates and the recovery obtained were materially better.

Concentration tests on molybdenite ore by the Elmore vacuum-flootation process.^a

Per cent MoS ₂ .			Recovery, per cent.	Remarks.
In ore.	In tailings.	In con- centrates.		
5.67	0.42	68.00	93.2	Gangue principally feldspar.
3.83	.10	85.95	98.1	Gangue principally magnetite and garnet.

^a Converted from figures given by A. S. Elmore, Vacuum flootation process for concentration: Eng. and Min. Jour., vol. 83, 1907, pp. 908, 909.

It is reported that the Elmore process is being used for treating molybdenite at two mines in Norway and that large quantities of concentrates have already been shipped.^b The writer believes that these plants are as yet the only ones in which any type of oil concen-

^a Hoover, T. J., op. cit., pp. 164-166.

^b Molybdenum recovery by Elmore process: Eng. and Min. Jour., vol. 99, 1915, p. 907.

tration has been attempted for concentrating molybdenite on a commercial basis.

The results of several large-scale concentration tests by the Ore Concentration Co. (Ltd.), of London, of four different lots of molybdenite ore by the Elmore process are given in the accompanying table. The results of these tests, which were made with ore crushed through 30 mesh, compare favorably with those given in the preceding table and indicate in general what might be expected in the treatment of any molybdenite ore to which the process is adapted.

Concentration tests of molybdenite ore by the Elmore vacuum-flotation process.^a

Weight of ore treated, tons.	Per cent MoS_2 in con- centrates.	Recovery, per cent.
32.0	85.68	91.5
32.0	86.30	94.5
37.0	84.25	89.7
3.5	83.00	90.0
104.5	84.80	91.7

^a Molybdenum recovery by Elmore process: Eng. and Min. Jour., vol. 99, 1915, p. 907.

REMOVAL OF ACCOMPANYING METALLIC SULPHIDES.

When other metallic sulphides, such as chalcopyrite, pyrite, or pyrrhotite, accompany molybdenite they are concentrated with the latter mineral by both electrostatic and flotation methods. The presence of pyrite or pyrrhotite in the concentrates is undesirable only in that it lowers the grade of the product, but chalcopyrite, bornite, or other copper sulphides are objectionable in that if the concentrates contain more than 1 or 2 per cent of copper they are practically unsalable, and even small percentages of copper greatly lower their value.

Various methods have been suggested for removing the other sulphides either before or after the concentration of the molybdenite. Most of these methods depend on the ore or concentrates being lightly roasted. In this way the larger part of the pyrite and chalcopyrite are rendered magnetic and may be removed by means of a magnetic separator, or, through the formation of a coating of oxide on the surface of each particle, the pyrite and chalcopyrite in the ore are readily wetted and sink if the material is subjected to flotation. It is at once evident that these new properties imparted to the pyrite and chalcopyrite by roasting can be taken advantage of either separately or in a combination of processes. In the writer's opinion it is cheaper and more effective as regards ultimate recovery of molybdenite to remove the other sulphides after concentration rather than before. No matter how carefully conditions of roasting are controlled some

of the molybdenite will be partly converted to oxide on the surface of the individual grains, and this coating will entail some loss of the molybdenite whether the material is treated by flotation or on an electrostatic separator. So far as recovery of the molybdenite is concerned it is, therefore, advisable to roast the combined concentrates and remove the oxidized pyrite and chalcopyrite by magnetic separation.

On the other hand, even with the most carefully regulated roasting, all the pyrite and chalcopyrite do not become magnetic. If the non-magnetic product from the magnetic separator contains an appreciable amount of copper its retreatment by flotation may be advisable in order to further rid the molybdenite from grains of chalcopyrite and pyrite which, although nonmagnetic, are covered with a film of oxide that will cause them to become wet and to sink. In other cases it may be advisable to dispense entirely with magnetic separation and to treat the lightly roasted concentrate directly by flotation.

A method for separating chalcopyrite, which takes advantage of the oxidation of the surface of the particles at ordinary temperatures, is suggested by a correspondent of the Engineering and Mining Journal. In regard to a molybdenite ore containing chalcopyrite, he states that: "After grinding the ore to 40 mesh, it was dampened and dried. Under these conditions 90 per cent of the MoS₂ will float, and practically every particle of the chalcopyrite sinks. This furnishes a cheaper method than to roast the mixed flotation concentrates with the intention of removing the copper ore magnetically."^a

Wood suggests treating the combined concentrates on the ordinary type of wet concentrating table with the idea of separating the molybdenite in what is usually the tailing product.^b The author believes that this method would not be particularly effective. Moreover, inasmuch as the presence of even a small fraction of 1 per cent of copper is objectionable in the concentrates, it is doubtful whether any of the processes suggested above are commercially capable of reducing the copper to 0.1 per cent., for example, in any material in which the ratio of copper sulphide to molybdenite is relatively large. For such ore chemical methods of separation will probably have to be used.

SUMMARY.

Each particular molybdenite ore presents its own concentration problems. Usually one of the methods, or a combination of the methods, discussed above will give satisfactory results, but in some instances other ore-dressing processes must be employed in conjunction with them.

^a Molybdenum, tungsten, and uranium ores, Eng. and Min. Jour., vol. 97, 1913, p. 114.

^b Wood, H. E., The Wood flotation process: Trans. Am. Inst. Min. Eng., vol. 44, 1912, p. 111.

CONCENTRATION OF WULFENITE ORES.

Unlike the concentration of molybdenite, the treatment of wulfenite ores presents few difficulties. Not only are the ordinary wet processes of concentration by jigs, tables, vanners, slimers, etc., such as are usually employed in the treatment of ores of lead, copper, and zinc, adapted to the concentration of wulfenite, but, when properly applied, they result in a high extraction of the mineral. Moreover, even the finest particles of wulfenite are readily wetted; hence sliming of the ore does not occasion the considerable losses that would occur under similar circumstances in the treatment of most metallic sulphides, such as galena and chalcopyrite, as these minerals float readily when finely divided. On account of the high specific gravity of wulfenite (6.7 to 7) it is readily separated from all of the gangue minerals with which it occurs. It is, however, frequently associated with vanadinite (specific gravity, 6.66 to 7.23), from which it can not be separated by wet methods, also with cerussite (specific gravity, 6.46 to 6.57), and anglesite (specific gravity, 6.12 to 6.39), from which it can be only partly separated. Occasionally small quantities of other lead minerals of high specific gravity, such as galena (specific gravity, 7.4 to 7.6), pyromorphite (specific gravity, 6.5 to 7.1), and mimetite (specific gravity, 7.0 to 7.25), occur with wulfenite and are then recovered in the wulfenite concentrate. The presence or absence of these other heavy minerals in the ore determines largely the grade of wulfenite concentrates that can be made. Theoretically, a concentrate consisting entirely of pure wulfenite contains 39.23 per cent molybdic trioxide (MoO_3), and with many ores a product with 34 to 36 per cent molybdic trioxide is easily obtained, whereas with others a concentrate containing even 20 per cent molybdic trioxide is obtained with difficulty owing to the presence of considerable percentages of vanadinite, cerussite, etc. The costs of concentrating wulfenite ores by wet processes are in general comparable to those of treating ores of galena, sphalerite, chalcopyrite, etc., by similar methods.

Many deposits of wulfenite ore are situated at considerable distances from water supplies of sufficient magnitude to furnish the quantities requisite for wet concentration. It is, therefore, of interest to note that wulfenite can be concentrated successfully by pneumatic processes, and that there are pneumatic separators of various types, such as tables and jigs, now on the market that without doubt can effect nearly as high an extraction and make as good grade of concentrates as can be obtained by wet methods. The cost of separation by pneumatic processes is, of course, greater than by wet methods.

CONCENTRATION TESTS OF WULFENITE ORE FROM OLD YUMA MINE, NEAR TUCSON, ARIZ.

The tables following give the results obtained by the author from a series of concentration tests of wulfenite ore from the Old Yuma mine, 14 miles northwest of Tucson, Ariz. The tests were not conducted with the idea of deriving the best method of treatment for the ore in question, but to show the wide range of processes that may be successfully applied to wulfenite ores in general. The ore used was of high grade, containing approximately 6 per cent molybdic trioxide. The gangue was an iron-stained siliceous rock in which the wulfenite was present in crystals varying in size from minute specks up to one-half inch in maximum diameter. A sample of the original ore weighing 120 pounds was crushed in a small jaw crusher to pass through a 3-mesh screen, and divided into six lots by careful sizing. The first three of these lots, embracing material through 3-mesh on 20-mesh, were treated in a hydraulic pulsator jig. The next two lots, embracing material through 20-mesh on 100-mesh, were concentrated in a pneumatic jig, and the last lot of material through 100-mesh was run on a concentrating table of common make.

Concentration tests, on machines of various types, of wulfenite ore from the Old Yuma mine, 14 miles northwest of Tucson, Ariz.

TEST 1. CONCENTRATION ON HYDRAULIC PULSATATOR JIG.

Item.	Through 3-mesh, on 6-mesh.				Through 6-mesh, on 10-mesh.			
	Ore.	Concen- trates.	Mid- dlings.	Tailings.	Ore.	Concen- trates.	Mid- dlings.	Tailings.
Weight, pounds.....	32.50	3.54	1.46	27.50	27.00	4.73	1.00	21.27
Per cent MoO ₃	α 4.59+	36.43	8.46	.29	α 6.14+	32.76	5.13	.37
Weight MoO ₃ , pounds.....	1.494	1.290	.124	.080	1.680	1.550	.051	.079
Extraction MoO ₃ , per cent.....		86.35	8.30	.....		92.26	3.04	.....
Loss MoO ₃ , per cent.....				5.35				4.70

Item.	Through 10-mesh, on 20-mesh.				Total.			
	Ore.	Concen- trates.	Mid- dlings.	Tailings.	Ore.	Concen- trates.	Mid- dlings.	Tailings.
Weight, pounds.....	18.00	4.55	1.57	11.88	77.50	12.82	4.03	60.65
Per cent MoO ₃	α 10.01+	34.98	11.45	.25	α 6.42+	α 34.57+	α 8.80+	α .31+
Weight MoO ₃ , pounds.....	1.802	1.592	.180	.030	4.976	4.432	.355	.189
Extraction MoO ₃ , per cent.....		88.35	9.99	.....		89.07	7.13	.....
Loss MoO ₃ , per cent.....				1.66				3.80

a Calculated.

Concentration tests, on machines of various types, of wulfenite ore from the Old Yuma mine 14 miles northwest of Tucson, Ariz.—Continued.

TEST 2. CONCENTRATION ON PNEUMATIC PULSATOR JIG.

Item.	Through 20-mesh, on 60-mesh.			Through 60-mesh, on 100-mesh.			Total.		
	Ore.	Concen-	Tailings.	Ore.	Concen-	Tailings.	Ore.	Concen-	Tailings.
Weight, pounds.....	21.00	4.05	16.95	7.00	0.80	6.20	28.00	4.85	23.15
Per cent MoO ₃	^a 7.60+	33.48	1.42	^a 3.94+	29.23	.67	^a 6.68+	^a 32.78+	^a 1.22+
Weight MoO ₃ , pounds.....	1.597	1.356	.241	.276	.234	.042	1.873	1.590	.283
Extraction MoO ₃ , per cent.....	84.91				84.78			84.89	
Loss MoO ₃ , per cent.....		15.09				15.22			15.11

TEST 3. CONCENTRATION ON DIAGONAL-RIFFLE OSCILLATING TABLE (WET).

Item.	Through 100-mesh.		
	Ore.	Concen-	Tailings.
Weight, pounds.....	11.50	0.78	10.72
Per cent MoO ₃	^a 2.33+	21.98	.91
Weight MoO ₃ , pounds.....	.269	.171	.098
Extraction MoO ₃ , per cent.....		63.57	
Loss MoO ₃ , per cent.....			36.43

^a Calculated.

SUMMARY.

Item.	Ore.	Concen-	Middlings.	Tailings.
Total weight, pounds.....	117.00	18.45	4.03	94.52
Total weight MoO ₃ , pounds.....	7.118	6.193	.355	.570
Per cent MoO ₃	^a 6.08+	^a 33.56+	^a 8.80+	^a .60+
Extraction MoO ₃ , per cent.....		87.00	4.99	
Loss MoO ₃ , per cent.....				8.01

^a Calculated.

Distribution of wulfenite, and recoveries and losses, according to sizes in tests 1, 2, and 3.

Machine used.	Size of material.	Per cent of total MoO ₃ in—			
		Feed.	Concen-	Middlings.	Tailings.
Hydraulic pulsator jig...	Through 3-mesh, on 6-mesh	20.98	18.12	1.74	1.12
	Through 6-mesh, on 10-mesh	23.60	21.77	.72	1.11
	Through 10-mesh, on 20-mesh	25.32	22.37	2.53	.42
Pneumatic pulsator jig..	Through 3-mesh, on 20-mesh.	69.90	62.26	4.99	2.65
	Through 20-mesh, on 60-mesh.	22.44	19.05		3.39
	Through 60-mesh, on 100-mesh.	3.88	3.29		.59
Concentrating table.....	Through 20-mesh, on 100-mesh.	26.32	22.34		3.98
	Through 100-mesh.....	3.78	2.40		1.38
	Total.....	100.00	87.00	4.99	8.01

DISCUSSION OF RESULTS OF TESTS.

The results obtained by treatment on the hydraulic pulsator jig show that the concentrates obtained averaged 34.57 per cent molybdic trioxide (MoO_3), which corresponds to 88.12 per cent pure wulfenite, and that the extraction in these concentrates was 89.07 per cent. The total middlings, which amounted to only 4.03 pounds, or 5.2 per cent of the feed, accounted for 7.13 per cent of the remaining molybdenum, and the bulk of the wulfenite contained in them could without doubt have been recovered as a high-grade concentrate by recrushing and treating the product on concentrating tables, even though the middlings contained considerable cerussite. It will be noted that the tailings averaged only 0.31 per cent molybdic trioxide, and although they amounted to 78.26 per cent by weight of the feed, the loss of wulfenite in them was only 3.8 per cent of the total quantity in the feed. In this instance, the ore through 10-mesh and on 20-mesh was jigged only to show that the method was applicable to treating material of this fineness. In commercial work it would probably be preferable to treat this size of wulfenite ore on concentrating tables, as in general more expert attention is required in the successful operation of jigs than in the use of tables.

The tests on the air pulsator jig were made to indicate the applicability of pneumatic processes to wulfenite ores in deposits situated at such distances from water supplies as to make wet concentration out of the question. A summary of the tests shows that the concentrates averaged 32.78 per cent molybdic trioxide, corresponding to 83.56 per cent pure wulfenite, and that the extraction in the concentrates was 84.89 per cent. No middling products were made, and for that reason the tailings were richer in wulfenite than they otherwise would have been. At the end of the two runs a perfect separation of the concentrates and tailings remaining in the jig was impossible, and in the effort to keep the concentrates clean a small quantity of them was skimmed off with the tailings. This procedure also lowered the extraction. Further, closer sizing of the material before treatment would, without doubt, have been beneficial. However, the tests demonstrated that an excellent grade of concentrates can be made by a pneumatic process, and considering all the conditions, the average extraction of 84.89 per cent compares favorably with the average extraction of 89.07 per cent made from the coarser sizes of material by the hydraulic pulsator jig, and it is probably little less than that which would have been obtained if the material had been treated by wet concentration on tables.

A common make of oscillating table with riffles terminating in a diagonal line across the deck was used for the wet concentration of the material that passed through a 100-mesh screen. A good

marketable grade of concentrates was made, but the extraction (63.57 per cent) was poor. The results indicate that a considerable portion of the material was too fine to be treated efficiently on this type of machine and that the ore should be further sized or classified and the finer part treated on a slime table.

Summarizing the results of the three series of tests, it will be seen that the average molybdic trioxide content of the total concentrates, total middlings, and total tailings was 33.56 per cent, 8.80 per cent, and 0.60 per cent, and that the extraction in the concentrate was 87 per cent, and in the middlings 4.99 per cent, whereas the total loss in the tailings was 8.01 per cent.

The table giving the distribution of wulfenite and the recoveries and losses in the various sizes of material, shows that practically 70 per cent of the total wulfenite in the ore was contained in the material through 3-mesh and on 20-mesh, and that out of this amount 62.26 per cent was recovered in the concentrates from the hydraulic pulsator jig, whereas 4.99 per cent more was contained in the middlings from the jig, a total recovery of 67.25 per cent. The table further shows that out of 26.32 per cent of the total wulfenite in the ore contained in the material through 20-mesh and on 100-mesh, the pneumatic pulsator jig recovered 22.34 per cent. Only 3.78 per cent of the wulfenite content of the ore was finer than 100-mesh, and of this amount the concentrating tables recovered 2.4 per cent.

Although the tests discussed above were not conducted with the idea of deriving a method of treatment, the results indicate in a general way the procedure that should be adopted. In the author's opinion the ore could be treated efficiently by wet concentration approximately as follows:

After the ore has been crushed in a jaw or crusher in gyratory crushers to about $\frac{1}{2}$ -inch size it should be further crushed in rolls to about $\frac{1}{4}$ -inch and the product screened into three series of sizes. Approximately, these sizes should be as follows: Through 4-mesh and on 8-mesh, and through 8-mesh and on 12-mesh, these two sizes to be treated on jigs; through 12-mesh and on 20-mesh, through 20-mesh and on 40-mesh, through 40-mesh and on 80-mesh, and through 80-mesh and on 120-mesh, these four sizes to be treated on concentrating tables, and the material through 120-mesh to be treated on slime tables. The jigs should be operated so as to obtain as clean concentrates and tailings as possible, and the middlings, after recrushing (perhaps through 20-mesh), should be appropriately sized for reconcentration by the tables.

In the operation of the tables the price received for various grades of wulfenite concentrates would determine where the cut between concentrates and tailings should be made. It might be advanta-



A. TAILING PILES CONTAINING WULFENITE, FROM STAMP AND CYANIDE MILLS,
MAMMOTH, ARIZ. LOADING TUNNEL AND TRACK TO WULFENITE MILL IN THE
FOREGROUND.



B. BOYKIN & HEREFORD WULFENITE MILL, MAMMOTH, ARIZ.

geous, from a commercial standpoint, to sacrifice something on the recovery in order to make an especially high grade of concentrates.

The author is confident that if the process described above was applied on ore similar to that treated it would result in at least a 90 per cent recovery of the wulfenite as a high-grade concentrate containing 30 per cent or more of molybdic trioxide.

It is of interest to note that the particular lot of ore used in the tests assayed 3.64 ounces of gold per ton and that a microscopic examination showed that much of the gold was contained as native metal in the wulfenite crystals themselves. As far as known, this is the first time that the presence of visible gold has been reported in wulfenite. Further, it was ascertained that the gold was seemingly confined to dark-colored crystals and that the more plentiful orange-colored crystals were free from the element. In order to verify the results of the microscopic examination, two lots of crystals were hand picked from the coarser sizes of concentrates obtained by jiggling. One lot consisted of clear, orange-yellow crystals, and the other of dark-brown to almost black crystals. These lots were crushed and assayed. Two assays of the yellow material failed to show even a trace of gold, whereas two assays of the dark crystals yielded 143.32 and 138.02 ounces per ton, thus proving conclusively that the gold was confined to the latter crystals. The author believes that a considerable proportion of the dark color of these crystals is due to minute particles of gold.

It is regretted that owing to the removal of considerable material from the coarser sizes of jigged concentrates for experimental purposes, no statement can be made regarding the recovery of gold in the concentrates as a whole. However, it would probably be somewhat less than the corresponding recovery of wulfenite or of molybdic trioxide, as no doubt the cerussite in the ore contains some gold. For example, the concentrates and tailings derived by jiggling the material through 20-mesh on 60-mesh assayed 15.36 and 0.82 ounces of gold per ton. Calculated from these assays, the gold content of the feed was 3.62 ounces per ton, and the recovery in the concentrates was 81.74 per cent, or slightly less than the corresponding recovery of molybdic trioxide, which was 84.91 per cent. The percentage of gold recovered, however, is probably almost identical with that of lead.

BOYKIN & HEREFORD WULFENITE MILL AT MAMMOTH, ARIZ.

At Mammoth, Pinal County, Ariz., there are large piles of tailings (Pl. XVIII, A) derived from ore from the Mammoth mine, about 3 miles distant at Schultz.^a This ore was originally crushed in a stamp

^a For description of the ore from this mine see p. 47.

mill and treated by amalgamation to recover its free-gold content. Later the tailings from this process were cyanided to extract the considerable part of the gold that was not free milling or had otherwise been lost in the first operation. Subsequently part of the resulting tailings was sluiced to recover the wulfenite content. This last operation was over a decade ago, and it probably supplied about 750 tons of wulfenite concentrates out of the 795 tons of combined wulfenite and molybdenite concentrates that constituted the total production of this county in 1903.^a

A part of these tailings piles is shown in Plate XV, *B*. They are estimated to contain 200,000 to 250,000 tons of material and 1 to 2 per cent of wulfenite. In 1914 Messrs. F. H. Hereford and R. O. Boykin, of Tucson, Ariz., who had obtained control of all but about 25,000 tons of this material, installed two concentrating tables in the mill building of the old cyanide plant and commenced the re-treatment of the tailings to recover the wulfenite. Operations were so successful that early in 1915 they entirely remodeled the small plant and increased the number of concentrating tables to seven. At this time (June, 1915) operations are being conducted as follows:

The tailings are dug from the tailings piles by means of a four-horse scraper and dragged up an incline to a loading platform, where they are dumped onto a coarse grizzly, which removes pieces of board, brush, etc., and allows the tailings to fall through into a car. The scraper used and the loading platform are shown in Plates XV, *B*, and XVIII, *A*. The cars into which the tailings are dumped, each having a capacity of slightly over a ton, are trammed by hand for several hundred feet to the foot of an incline leading to the mill bin. Here each car is hooked onto a cable and drawn up the incline to the upper edge of the bin, about 30 feet above the ground, and its contents dumped into the bin by hand. Each empty car is returned down the incline by gravity and run onto a switch to allow the next loaded car to pass and then trammed back into the tunnel beneath the loading platform to be refilled. Plate XVIII, *B*, shows a general view of the mill and its surroundings. It is understood that the work of scraping the tailings and placing them in the mill bin is let by contract and that the cost is about 14 cents per ton.

DISCUSSION OF FLOW SHEET.

In the following description of the operation of the mill the numbers refer to the flow sheet shown in figure 2. The mill bin or feed hopper, 1, has the form of an inverted square pyramid truncated parallel with its base, and holds about 40 tons. It is clearly shown in Plate XVIII, *B*. From this hopper the tailings are washed by a

^a Pratt, J. H., The steel-hardening metals: Mineral Resources U. S. for 1903, U. S. Geol. Survey, 1904, p. 308.

small stream of water over an inclined screen, 2, of about 4-mesh. The oversize on this screen is removed by hand and thrown away, and the undersize is carried through a launder into the mill building, where it discharges into a hindered-settling classifier, 3. The overflow from this classifier goes to a second hindered-settling classifier, 4, and the overflow from the second classifier to a third, 5, and so on through five classifiers. The overflow from the fifth classifier passes into a settling cone, 8, the overflow from which goes into the tailings

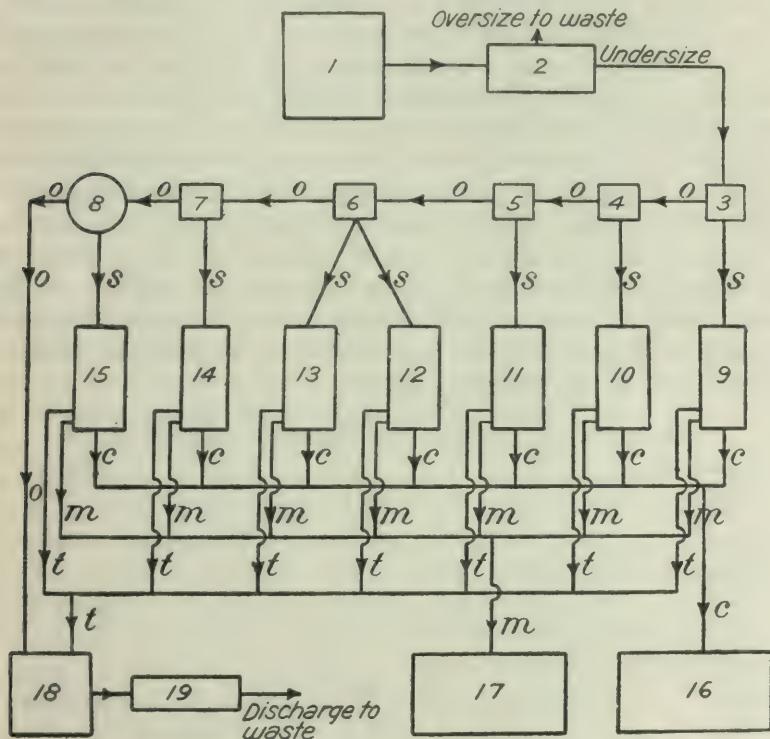


FIGURE 2.—Flow sheet of Boykin & Heresford wulfenite mill, Mammoth, Ariz. 1, Mill bin or hopper, having a capacity of about 40 tons; 2, inclined 4-mesh screen; 3 to 7, hindered-settling classifiers; 8, settling cone; 9 to 11, Overstrom tables; 12, Ludwig table; 13 to 15, Card tables; 16, concentrate storage; 17, middlings storage; 18, tailings sump; 19, Byron Jackson 3-inch "Dreadnaught" sand pump.

sump, 18. The spigot products from the first three classifiers, 3 to 5, are treated separately on three Overstrom tables, 9 to 11. The spigot product from the fourth classifier, 6, is divided into two parts, one of which goes to a Ludwig table, 12, and the other to a Card table, 13. The spigot products from the fifth classifier, 7, and from the settling cone, 8, are treated separately on two Card tables, 14 and 15. Each of the concentrating tables makes a middlings product, which goes to a storage bin, 17, for re-treatment. It is understood that these middlings are sometimes re-run on one of the concentrating tables, which is temporarily cut out of the mill system for their re-treatment, and

sometimes they are returned to the mill system as a whole. The tailings from all the tables go to the tailings sump 18, and the concentrates to storage bin 16, from which they are taken to be dried and sacked. The tailings are pumped from the tailings sump 18 by a Byron Jackson 3-inch "Dreadnaught" sand pump, 19, and discharged through a pipe onto a tailings pile a short distance from the mill.

Power is furnished by two Fairbanks-Morse oil engines of 12 and 20 horsepower. The smaller engine drives the sand pump 19, and the larger engine supplies power for operating the concentrating tables 9 to 15, a Byron Jackson 4-inch pump that supplies the plant with water, and a Browning 2-kilowatt dynamo which is rated to supply 16.6 amperes at 120 volts when run at 1,425 revolutions per minute. The dynamo furnishes electricity for lighting the mill and for illuminating the scraping and tramping operations on the tailings piles at night. The mill operates 24 hours a day and employs 10 to 12 men.

It is reported that about 2 tons of concentrates are obtained each day from the treatment of about 200 tons of tailings. A large sample of these concentrates, furnished to the author through the courtesy of Messrs. Hereford and Boykin, upon analysis yielded the results shown in the following table:

Analysis of wulfenite concentrates from mill at Mammoth, Ariz. a

Constituent.	Per cent.
MoO ₃	22.62
PbO.....	61.83
V ₂ O ₅	1.28
Fe ₂ O ₃ and Al ₂ O ₃	5.50
CuO.....	.65
SiO ₃	1.53
P ₂ O ₅.....	.30
SO ₃	1.96
CO ₂	3.20
Cl.....	.23
CaO, K ₂ O, etc.....	b .90
Total.....	100.00

The above analysis indicates the presence of the four principal mineral ingredients of the concentrates in the following percentages; Wulfenite, 57.63; cerussite, 18.32; vanadinite, 8.65; anglesite, 6.52; total, 91.12 per cent. As the last three minerals are of nearly the same specific gravity as wulfenite, the rather low molybdic trioxide content of the concentrates (22.62 per cent) is not surprising. In fact, with such relatively large percentages of these other heavy lead minerals in the feed, the writer does not see how any considerable betterment of the grade of concentrates could be expected. Inasmuch as over 1 per cent of tungsten had been reported to Messrs. Hereford

^a Analyst, H. A. Doerner, Bureau of Mines.

^b Approximate.

and Boykin in the analysis of a sample said to have represented a considerable tonnage of concentrates, it is of interest to note that none of that element was found in the analysis given above.

Although it would be difficult to improve greatly the grade of concentrates being made at this plant, the author is of the opinion that the capacity of a plant of this character could be greatly increased by the installation of an efficient screening system to remove the coarser particles of gangue before concentration on the tables, and that the extraction of wulfenite could be considerably improved by the treatment of the fines on slime tables or slime vanners.

RESULTS OF SCREEN TEST.

A screen test of a sample of concentrates was made, the results being presented below. The test showed that 93.6 per cent would pass through a 100-mesh screen, and that 76.2 per cent would pass through a 200-mesh screen. Further, it is reasonable to assume that the losses of wulfenite occurring in the mill are confined almost entirely to very fine material, so the relative proportion of fine to coarse wulfenite in the feed is probably even greater than indicated by the results of the screen test. It is obvious that, as the tables used for treating the finer sizes of material are not suited for treating slimes, a considerable loss of wulfenite must occur in their tailings. Moreover, the overflow from the settling cone in the mill is not treated at all but runs directly to the tailings sump. A panning test of this overflow product showed the presence of considerable fine wulfenite which could at least be partly recovered by allowing the overflow to settle in tanks and treating the slimes on slime tables or slime vanners. Further, as stated above, it is the author's opinion that a much better recovery would be effected if the finer part of the material, embracing the spigot product from the settling cone, and even, perhaps, the spigot product from the fifth, or final, classifier now being handled by the tables, were treated on concentrators adapted to handling slimes.

Results of screen test on wulfenite concentrates from mill at Mammoth, Ariz.

[Screen ratio, 1.414.]

Mesh.	Opening of holding screen.		Weight.	Per cent of total weight.	Per cent of cumulative weight.
	Inch.	Millimeter.			
On 48.....	0.0116	0.295	.41	2.7	2.7
Through 48, on 65.....	.0082	.208	.21	1.4	4.1
Through 65, on 100.....	.0058	.147	.35	2.3	6.4
Through 100, on 150.....	.0041	.104	.79	5.3	11.7
Through 150, on 200.....	.0029	.074	1.82	12.1	23.8
Through 200.....			1,142	76.2	100.0
Total.....			1,500	100.0	.....

The results of the screen test showed that only 2.7 per cent of the concentrates were caught on a 48-mesh screen. In other words, the original feed to the mill might be screened through a 48-mesh sieve, and by throwing away the oversize only 2.7 per cent of the material now recovered would be lost. It is regretted that the results of a screen test on the present feed to the mill are not available, so that the exact proportion of the gangue that might be eliminated by screening with a practically negligible loss might be accurately stated. The writer, however, is confident that more than one-quarter, and perhaps even one-half, of the total feed to the mill could be removed by screening to 40-mesh. That the capacity of the mill would be considerably increased by such a procedure is obvious, and the recovery and the grade of concentrates would probably also be benefited. In fairness to the operators of the mill it must be said that the screening system at the time of the author's visit (screening to about 4-mesh at the outlet of the mill bin and to about 8-mesh or 10-mesh through pieces of screen placed in the feed boxes of the concentrating tables), was only a temporary makeshift, and has doubtless been replaced by a more efficient system.

SELECTED BIBLIOGRAPHY ON MOLYBDENUM.

- ACKERMAN, EUGENE. Examen du marché de divers métaux—molybdène. Métaux et alliages, vol. 5, 1912, pp. 108–110. Describes uses of molybdenum, and lists principal localities in various countries from which its ores are derived.
- ANDREWS, E. C. Molybdenum. New South Wales Dept. of Mines and Agriculture, Geol. Survey, Mineral Resources No. 11, 1906, 17 pp. Describes occurrences of molybdenite and wulfenite ores in New South Wales.
- ANONYMOUS. Norwegian molybdenite. Eng. and Min. Jour., vol. 98, 1914, p. 820. Describes several Norwegian deposits and gives data as to production.
- Occurrence and uses of molybdenum ores. Bull. Imperial Inst., vol. 6, 1908, pp. 181–191. Summary of facts in regard to uses and to production and occurrence in various countries.
- Molybdenum, tungsten, and uranium ores. Eng. and Min. Jour., vol. 97, 1914, p. 114. Describes method of separating copper sulphides from molybdenite by flotation after superficial oxidation, obtained by wetting and drying.
- AUCHY, GEORGE. The rapid determination of molybdenum in steel. Iron Age, vol. 70, Nov. 20, 1902, p. 4.
- BAAR, N. Über die Legierungen des Molybdäns mit Nickel des Mangans mit Thallium und des Kalzium mit Magnesium, Thallium, Blei, Kupfer, und Silber. Ztschr. anorg. Chem., vol. 70, 1911, pp. 352–394. Study of constitution of the alloys.
- BALL, L. C. Rare-metal mining in Queensland—résumé of recent field studies. Queensland Govt. Min. Jour., vol. 14, 1913, pp. 4–7. Describes principal molybdenite deposits.
- The wolfram, molybdenite, and bismuth mines of Bamford. Queensland Mines Dept., Geol. Surv. Pub. 248.
- BORNEMANN, K. Die Binären Metallegierungen—Legierungen des Molybdäns und des Wolframs. Metallurgie, vol. 9, 1912, pp. 384–392. Describes iron-molybdenum, nickel-molybdenum, iron-tungsten, alloys, etc.
- BROWN, A. P. The crystallization of molybdenite. Proc. Acad. Nat. Sci., Philadelphia, 1896, pt. 1, pp. 210–211.
- CAMERON, W. E. Wolfram and molybdenite mining. Queensland Govt. Min. Jour., vol. 5, 1904, pp. 62–65. History, statistics, and geology of principal Queensland deposits.
- Wolfram, molybdenite, and bismuth mining at Wolfram Camp, Hodgkinson goldfield. Queensland Govt. Min. Jour., vol. 4, 1903, pp. 350–352. Deals with geology, working, etc., of principal mines in this district of Queensland.
- CLENNELL, J. E. Molybdenum in cyanide solutions. Eng. and Min. Jour., vol. 97, 1914, pp. 363–364. Describes action of molybdenum in cyanide solutions.
- COOLIDGE, W. D. Some applications of wrought tungsten and molybdenum. Jour. Ind. and Eng. Chem., vol. 4, 1912, pp. 2–4. Describes uses of molybdenum for electrical contacts and winding electrical-resistance furnaces, etc.
- CROOK, A. R. Molybdenite at Crown Point, Washington. Bull. Geol. Soc. Am., vol. 15, 1904, pp. 283–288. Describes deposit and discusses petrographic relationships and accompanying minerals in molybdenum deposits in general.
- DARROCH, JAMES, and MEIKLEJOHN, C. A. A rapid method of determining molybdenum. Eng. and Min. Jour., vol. 82, 1906, p. 818. See Erratum, vol. 83, 1907, p. 177.
- DAVIS, R. S. Notes on technical analysis—analysis of wulfenite ores. Met. and Chem. Eng., vol. 9, 1911, pp. 458–459.

- DE BENNEVILLE, J. S. Some alloys of iron with molybdenum, tungsten, and chromium as solutions. *Jour. Am. Chem. Soc.*, vol. 16, 1894, pp. 735-757.
- Ternary alloys of iron with chromium, molybdenum, and tungsten. *Jour. Iron. and Steel Inst.*, 1895, No. 1, pp. 202-248. A chemical study of the constitution of various alloys.
- DEBRAY, H. Recherches sur le molybdène. *Compt. rend.*, vol. 46, 1858, pp. 1098-1102. Describes early experiments in the production of metallic molybdenum.
- DITTUS, E. J., and BOWMAN, R. G. The direct production of molybdenum steel in the electric furnace. *Trans. Am. Electrochem. Soc.*, vol. 20, 1911, pp. 355-372. Describes in detail experiments in direct electric smelting of molybdenite concentrates.
- EMMONS, W. H. Some ore deposits in Maine and the Milan mine, New Hampshire. *U. S. Geol. Survey Bull.* 432, 1910, pp. 21, 42, 47-49. Describes occurrence of molybdenite in several deposits.
- ESCARD, J. Méthodes électrochimiques et alumino-thermiques pour la préparation de la fonte de molybdène et des ferro-molybdènes. *La Lumière Électrique*, vol. 7, 1909, pp. 200-206. Describes preparation of pure molybdenum.
- EVANS, J. C. Determination of molybdenum in wulfenite. *West. Chemist and Metallurgist*, vol. 3, 1907, pp. 218-219.
- FAHRENWALD, F. A. A development of practical substitutes for platinum and its alloys, with special reference to alloys of tungsten and molybdenum. *Bull. 109, Am. Inst. Min. Eng.*, January, 1916, pp. 103-149. Describes investigation undertaken by research foundation of the National Dental Association. Pure ductile molybdenum coated with a precious metal or alloy in many ways superior to platinum or its alloys for dental work.
- FINK, C. G. Ductile tungsten and molybdenum. *Trans. Am. Electrochem. Soc.*, vol. 17, 1910, pp. 229-234. Compares tensile strength, specific gravity, resistivity, etc., of tungsten and molybdenum wire.
- FRIEND, N. J., and MARSHALL, C. W. The influence of molybdenum on the corrodibility of steel. *Jour. Iron and Steel Inst.*, vol. 89, No. 1, 1914, pp. 503-507. Describes various tests in fresh, salt, and acid waters, etc.
- GIN, G. Memoir on the methods of treatment of simple and complex ores of molybdenum, tungsten, uranium, vanadium. Part I. Molybdenum. *Trans. Am. Electrochem. Soc.*, vol. 12, 1907, pp. 411-474. Deals chiefly with the manufacture of ferromolybdenum in the electric furnace.
- Sur le traitement de la wulfénite pour ferromolybdène à basse teneur en carbone. *Proc. 7th Int. Cong. Appl. Chem.*, vol. 10, 1909, p. 10. Describes method of treating wulfenite to obtain ferromolybdenum of low-carbon content.
- GLEDHILL, J. M. The development and use of high-speed tool steel. *Jour. Iron and Steel Inst.*, 1904, No. 2, pp. 127-182. General description covering heat treatment, tests, etc., of tool steels, including molybdenum-chromium and tungsten-molybdenum-chromium steels.
- GUICHARD, M. Sur la molybdenite et la préparation au molybdène. *Compt. rend.*, vol. 122, 1896, pp. 1270-1272. Describes the decomposition of molybdenite in the electric arc.
- GUILD, F. N. The composition of molybdite from Arizona. *Am. Jour. Sci.*, ser. 4, vol. 23, 1907, pp. 455-456. Gives analysis of mineral from Santa Rita mountains.
- GUILLET, LEON. Propriétés et constitution des aciers au molybdène, *Compt. rend.*, vol. 139, 1904, pp. 540-542. Describes experiments on various molybdenum steels, showing strength and hardening, and tempering properties.
- Recherches sur les aciers au molybdène. *Génie Civil*, vol. 45, 1904, pp. 242-244. Results of a series of systematic tests, with microphotographs of molybdenum steels.

- HÄNIG, A. Die modernen Eisenlegierungen und ihre Verwendung in der Eisen- und Stahlindustrie. Discusses ferromolybdenum. *Electrochem. Ztschr.*, Jahrg. 20, November, 1913, pp. 211-213. Discusses modern ferroalloys and their application in the iron and steel industry.
- HAYNES, ELWOOD. Alloys of cobalt with chromium and other metals. *Trans. Am. Inst. Min. Eng.*, vol. 44, 1912, pp. 573-577. Describes a cobalt-chromium-molybdenum alloy, and also a chromium-cobalt-tungsten-molybdenum alloy.
- HESS, F. L. Some molybdenum deposits of Maine, Utah, and California. U. S. Geol. Survey Bull. 340, 1908, pp. 231-240. Describes molybdenite deposits at Cooper, Catherines Hill, and other localities in Maine, and at Corona, Cal., also a wulfenite deposit at Alta, Utah.
- Molybdenum. Mineral Resources U. S. for 1906, U. S. Geol. Survey, 1907, pp. 527-529; Mineral Resources U. S. for 1908, U. S. Geol. Survey, 1909, pp. 745-747.
- HIBBARD, H. D. Manufacture and uses of alloy steels, Bureau of Mines Bull. 100, 1915, pp. 58-59. The use of molybdenum in high-speed tool steel is discussed.
- HILLEBRAND, W. F. Distribution and quantitative occurrences of vanadium and molybdenum in rocks of the United States. *Am. Jour. Sci.*, ser. 4, vol. 6, 1898, pp. 209-216; U. S. Geol. Survey Bull. 167, 1900, pp. 49-55.
- HILLS, B. W. The molybdenite deposits of Tunk Pond, Maine. *Min. World*, vol. 31, 1909, pp. 323-324. Describes deposits with special reference to their geology, lists accompanying minerals, and describes a phosphate of molybdenum called "knightite."
- INGERSOLL, C. A. On hemimorphic wulfenite crystals from New Mexico. *Am. Jour. Sci.*, ser. 3, vol. 48, 1894, pp. 193-195. Describes hemimorphic crystals from Turquoise mines in the Jarilla Mountains, Dona Ana County.
- JOHNSTON, R. A. A., and WILLIMOTT, C. W. Molybdenum and tungsten. *Mineral Resources of Canada*, Geol. Survey of Canada, Bull. 872, 1904, 16 pp. Describes various Canadian occurrences.
- JORISSEN, A. Sur la diffusion du molybdène dans le terrain houiller de Liège. *Bull. Soc. Chem. de Belgique*, vol. 27, 1913, pp. 21-25.
- KEENEY, R. M. The production of steels and ferroalloys directly from ore in the electric furnace. *Jour. Iron and Steel Inst.*, Carnegie Scholarship Memoirs, vol. 4, 1912, pp. 108-184. Describes production of molybdenum steel.
- Electric smelting of chromium, tungsten, molybdenum, and vanadium ores. *Trans. Am. Electrochem. Soc.*, vol. 24, 1913, pp. 167-189. Gives historical and experimental data with regard to the manufacture of ferromolybdenum, pp. 184-188.
- LAUTSCH and TAMMAU, J. Über die Legierungen des Eisens mit Molybdän. *Ztschr. anorg. Chem.*, vol. 55, 1907, pp. 386-401. Discusses iron molybdenum alloys.
- LEHMER, C. Elektrisches verschmelzen sulfidischer Erze und Huttenprodukte unmittelbar auf Metall. *Metallurgie*, vol. 3, 1906, pp. 549-555 and pp. 596-602. Describes method of producing ferromolybdenum, chrome molybdenum, nickel molybdenum, manganese molybdenum, and copper molybdenum.
- LYON, D. A., KEENEY, R. M., and CULLEN, J. F. The electric furnace in metallurgical work. *Bureau of Mines Bull.* 77, 1914, pp. 146-151. Discusses electric smelting of molybdenite and the production of ferromolybdenum.
- MENNICKE, HANS. Die Metallurgie des Wolframs, 1911, 416 pp. Treats of the preparation of molybdenum, ferromolybdenum, etc. (pp. 94-100).
- The metallurgy of molybdenum and vanadium. *Elektrochem. Ztschr.*, October, 1913.
- MEYERS, R. E. Commercial manipulation of refractory elements for incandescent-lamp purposes. *Trans. Am. Inst. Chem. Eng.*, vol. 3, 1910, pp. 172-187. Interesting data on ductile metallic molybdenum.

- MILLS, S. D. Molybdenite. Report of the Bureau of Mines, Ontario, 1902, pp. 45-48. Describes various deposits in Haliburton.
- MOISSAN, HENRI. Préparation et propriétés du molybdène pur fondu. *Compt. rend.*, vol. 120, 1895, pp. 1320-1326.
- The electric furnace. Translated from the French by Victor Lehuer, 1904, 305 pp. Deals with the preparation of metallic molybdenum (pp. 155-161).
- MOSES, A. J. The crystallization of molybdenite. *Am. Jour. Sci.*, ser. 4, vol. 17, 1904, pp. 359-364.
- NORTHRUP, E. F. Tungsten and molybdenum—their thermal e. m. f. *Met. and Chem. Eng.*, vol. 11, January, 1913, p. 45. Gives temperature curve of the tungsten-molybdenum thermocouple from 1° to 1,000° C.
- OBLASKI, J. Report on the mines of the Province of Quebec for the year 1898. Dept. Colonization and Mines, 1899, pp. 15-17. Describes molybdenite deposits in Quebec.
- OHLY, J. Molybdenite; its determination, detection, and uses. *Min. Reporter*, vol. 50, 1904, pp. 10-11.
- PLUMMER, JOHN. Molybdenite deposits in Australia. *Min. World*, vol. 26, 1907, pp. 421-422. Describes deposits and methods of mining and preparation in New South Wales and Queensland.
- PIRANI, M. V., and MEYER, A. R. Über den Schmelzpunkt des Wolframs und des Molydäns. *Ver. deut. phys. Gesell.*, vol. 14, 1912, pp. 426-428. The melting point of molybdenum is given as 2,450° C. +30°, that of tungsten as 3,100° C. ±60°.
- PORTEVIN, A. M. Contribution to the study of the special ternary steels. *Carnegie Scholarship Memoirs, Iron and Steel Inst. (London)*, vol. 1, 1909, pp. 275-276, 330-333. Gives tensile and shearing strength of various molybdenum steels and data on electrical resistance.
- PRATT, J. H. The steel and iron hardening metals, *Mineral Resources U. S. for 1904*, U. S. Geol. Survey, 1905, pp. 338-343.
- RUDER, W. E. Solubility of wrought tungsten and molybdenum. *Jour. Am. Chem. Soc.*, vol. 34, 1912, pp. 387-389. Gives data on solubility in common acids and alkalies.
- SAINT-SMITH, E. C. Molybdenite in the Stanthorpe-Ballandean districts, Southern Queensland. *Queensland Govt. Min. Jour.*, vol. 15, 1914, pp. 184-189.
- SCHALLER, W. T. Notes on powellite and molybdate. *Am. Jour. Sci.*, ser. 4, vol. 25, 1908, pp. 71-75. Describes powellite from Llano County, Tex., and Nye County, Nev., also molybdate from Hortense, Colo.
- The chemical composition of molybdc ocher. *U. S. Geol. Survey Bull.* 490, 1911, pp. 84-82; *Am. Jour. Sci.*, ser. 4, vol. 23, April, 1907, pp. 297-303.
- Notes on powellite. *U. S. Geol. Survey Bull.* 490, 1911, pp. 80-83.
- SCHLIER, KARL. Über ein Molybdänbluerz-Vorkommen in Ober-Bayern. *Oester. Ztschr. Berg. und Hüttenwesen*, vol. 59, 1911, pp. 475-478. Describes an extensive wulfenite deposit in Upper Bavaria.
- SCHRADER, F. C., and HILL, J. M. Some occurrences of molybdenite in the Santa Rita and Patagonia mountains, Arizona. *U. S. Geol. Surv. Bull.* 430, 1910, pp. 154-163. Describes deposits at Helvetia and in Madera and Providencia canyons, also at Duquesne and in San Antonio Canyon.
- SMITH, G. O. A molybdenite deposit in eastern Maine. *U. S. Geol. Surv. Bull.* 260, 1905, pp. 197-199. Describes deposit at Cooper, Washington County.
- STEINHART, O. J. Metals and their ferroalloys used in the manufacture of alloy steels. *Trans. Inst. Min. and Met.*, vol. 15, 1905-1906, pp. 247-249. Describes ores and metallurgy of molybdenum.
- SWEEZEY, R. O. Molybdenite deposit at Turn Back Lake, Quebec. *Can. Min. Jour.*, vol. 34, 1913, pp. 190-191. Describes occurrence and exploration work.

- SWINDEN, THOMAS. A study of the constitution of the carbon-molybdenum steels, with an appendix on the mechanical properties of some low molybdenum-alloy steels. Carnegie Scholarship Memoirs, Iron and Steel Inst. (London), vol. 5, 1913, pp. 100-168. A study of the recalcenece curves, microstructure, and hardness of certain molybdenum steels as bearing on their constitution.
- . Carbon molybdenum steels. Carnegie Scholarship Memoirs, Iron and Steel Inst. (London), vol. 3, 1911, pp. 66-124. A study of the mechanical properties and electrical resistivity of certain molybdenum steels. A comparison with corresponding tungsten steels is of interest.
- TAYLOR, F. W. On the art of cutting metals. Trans. Am. Soc. Mech. Eng., vol. 28, 1907, pp. 31-350. Discusses molybdenum as a substitute for tungsten in high-speed tools, pp. 243-244.
- TREADWELL, W. D. Ueber die elektroanalytische Trennung des Kupfers von Wulfraum und Molybdän. Ztschr. Elektrochem., vol. 19, 1913, pp. 219-221.
- VIGOUROUX, E. Sur les ferromolybdènes purs. Compt. rend., vol. 142, 1906, pp. 889-891, 928-930. Describes various iron-molybdenum compounds.
- VON LIPIN, W. Einige Eigenschaften des Molybdänstahl. Stahl und Eisen, 1897, vol. 14, pp. 571-572. Describes series of comparative tests on molybdenum and tungsten steels.
- WALKER, T. L. On the molybdenum ores of Ontario and British Columbia, 1911, pp. 65-66. Summary report of the mines branch for the calendar year ended Dec. 31, 1910.
- . Report on the molybdenum ores of Canada. Canadian Dept. of Mines, Mine Branch, Ottawa, 1911, No. 93, 64 pp.
- WEINIG, A. J. Molybdenum in cyanide solutions. Eng. and Min. Jour., vol. 97, 1914, p. 773. Describes qualitative test for molybdenum with potassium sulphocyanide.
- WELLS, J. W. Molybdenite—its occurrence, concentration, and uses. Canadian Min. Rev., vol. 22, 1903, pp. 113-118. Gives results of concentration tests and describes occurrences and uses in Canada.
- WINNE, R. Small electric furnace with heating element of ductile molybdenum. Trans. Am. Electrochem. Soc., vol. 20, 1911, pp. 287-292. Describes crucible and tube furnace, in which wire is wound on the alundum and hydrogen is used to protect the metal.
- WOOD, H. E. Concentration of molybdenite ores. Eng. and Min. Jour., vol. 93, 1912, pp. 227-228. Describes Wood flotation apparatus and its application to molybdenite ores.
- . The Wood flotation process. Trans. Am. Inst. Min. Eng., vol. 44, 1912, pp. 684-701. Good description of Wood process and apparatus, with results of tests of various ores, including molybdenite.

PUBLICATIONS ON MINERAL TECHNOLOGY.

A limited supply of the following publications of the Bureau of Mines has been printed, and is available for free distribution until the edition is exhausted. Requests for all publications can not be granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

The Bureau of Mines issues a list showing all its publications available for free distribution as well as those obtainable only from the Superintendent of Documents, Government Printing Office, on payment of the price of printing. Interested persons should apply to the Director, Bureau of Mines, for a copy of the latest lists.

BULLETIN 16. The uses of peat for fuel and other purposes, by C. A. Davis. 1911. 214 pp., 1 pl., 1 fig.

BULLETIN 45. Sand available for filling mine workings in the Northern Anthracite Coal Basin of Pennsylvania, by N. H. Darton. 1913. 33 pp., 8 pls., 5 figs.

BULLETIN 64. The titaniferous iron ores of the United States, their composition and economic value, by J. T. Singewald, jr. 1913. 145 pp., 16 pls., 3 figs.

BULLETIN 81. The smelting of copper ores in the electric furnace, by D. A. Lyon and R. M. Keeney. 1915. 80 pp., 6 figs.

BULLETIN 84. Metallurgical smoke, by C. H. Fulton. 1915. 94 pp., 6 pls., 15 figs.

BULLETIN 85. Analyses of mine and car samples of coal collected in the fiscal years 1911 to 1913, by A. C. Fieldner, H. I. Smith, A. H. Fay, and Samuel Sanford. 1914. 444 pp., 2 figs.

BULLETIN 92. Feldspars of the New England and Northern Appalachian States, by A. S. Watts. 1915. 181 pp., 8 pls., 22 figs.

BULLETIN 100. Manufacture and uses of alloy steels, by H. D. Hibbard. 1915. 78 pp.

BULLETIN 106. The technology of marble quarrying, by Oliver Bowles. 1916. 174 pp., 12 pls., 23 figs.

TECHNICAL PAPER 8. Methods of analyzing coal and coke, by F. M. Stanton and A. C. Fieldner. 1913. 42 pp., 12 figs.

TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

TECHNICAL PAPER 32. The cementing process of excluding water from oil wells, as practiced in California, by Ralph Arnold and V. R. Garfias. 1912. 12 pp., 1 fig.

TECHNICAL PAPER 38. Wastes in the production and utilization of natural gas, and means for their prevention, by Ralph Arnold and F. G. Clapp. 1913. 29 pp.

TECHNICAL PAPER 39. The inflammable gases in mine air, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 2 figs.

TECHNICAL PAPER 43. The influence of inert gases on inflammable gaseous mixtures, by J. K. Clement. 1913. 24 pp., 1 pl., 8 figs.

TECHNICAL PAPER 50. Metallurgical coke, by A. W. Belden. 1913. 48 pp., 1 pl., 23 figs.

TECHNICAL PAPER 66. Mud-laden fluid applied to well drilling, by J. A. Pollard and A. G. Heggem. 1914. 21 pp., 12 figs.

TECHNICAL PAPER 68. Drilling wells in Oklahoma by the mud-laden fluid method, by A. G. Heggem and J. A. Pollard. 1914. 27 pp., 5 figs.

TECHNICAL PAPER 70. Methods of oil recovery in California, by Ralph Arnold and V. R. Garfias. 1914. 57 pp., 7 figs.

TECHNICAL PAPER 76. Notes on the sampling and analysis of coal, by A. C. Fieldner. 1914. 59 pp., 6 figs.

TECHNICAL PAPER 88. The radium-uranium ratio in carnotites, by S. C. Lind and C. F. Whittemore. 1915. 29 pp., 1 pl., 4 figs.

TECHNICAL PAPER 95. Mining and milling of lead and zinc ores in the Wisconsin district, Wisconsin, by C. A. Wright. 1915. 39 pp., 2 pls., 5 figs.

TECHNICAL PAPER 110. Monazite, thorium, and mesothorium, by K. L. Kithil, 1915. 32 pp., 1 fig.

TECHNICAL PAPER 111. Safety in stone quarrying, by Oliver Bowles. 1915. 48 pp., 5 pls., 4 figs.

TECHNICAL PAPER 126. The casting of clay wares, by T. C. McDougal. 1916. 26 pp., 6 figs.

TECHNICAL PAPER 128. Quarry accidents in the United States during the calendar year 1914, compiled by A. H. Fay. 1915. 45 pp.

PUBLICATIONS THAT MAY BE OBTAINED ONLY THROUGH THE SUPERINTENDENT OF DOCUMENTS.

The editions for free distribution of the following Bureau of Mines publications are exhausted, but copies may be obtained by purchase from the Superintendent of Documents, Government Printing Office, Washington, D. C., or can be consulted at public libraries. Prepayment of the price is required and should be made in cash (exact amount) or by postal or express money order payable to the Superintendent of Documents.

The Superintendent of Documents is an official of the Government Printing Office and is not connected with the Bureau of Mines.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp. 5 cents.

BULLETIN 11. The purchase of coal by the Government under specifications, with analyses of coal delivered for the fiscal year 1908-9, by G. S. Pope. 80 pp. 10 cents. Reprint of United States Geological Survey Bulletin 428.

BULLETIN 12. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer and E. J. Hoffman. 1911. 22 pp., 6 figs. 5 cents.

BULLETIN 19. Physical and chemical properties of the petroleums of the San Joaquin Valley, Cal., by I. C. Allen and W. A. Jacobs, with a chapter on analyses of natural gas from the southern California oil fields, by G. A. Burrell. 1911. 60 pp., 2 pls., 10 figs. 10 cents.

BULLETIN 26. Notes on explosive mine gases and dusts, with especial reference to explosions in the Monongah, Darr, and Naomi coal mines, by R. T. Chamberlin. 383 pp., 1 fig. 10 cents. Reprint of United States Geological Survey Bulletin 383.

BULLETIN 29. The effect of oxygen in coal, by David White. 80 pp., 3 pls. 20 cents. Reprint of United States Geological Survey Bulletin 382.

BULLETIN 38. The origin of coal, by David White and Reinhardt Thiessen, with a chapter on the formation of peat, by C. A. Davis. 1913. 390 pp., 54 pls. 80 cents.

BULLETIN 41. Government coal purchases under specifications, with analyses for the fiscal year 1909-10, by G. S. Pope, with a chapter on the fuel-inspection laboratory of the Bureau of Mines, by J. D. Davis. 1912. 97 pp., 3 pls., 9 figs. 15 cents.

BULLETIN 42. The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 116 pp., 2 pls., 23 figs. 20 cents.

BULLETIN 43. Comparative fuel values of gasoline and denatured alcohol in internal-combustion engines, by R. M. Strong and Lauson Stone. 1912. 243 pp., 3 pls., 32 figs. 20 cents.

BULLETIN 47. Notes on mineral wastes, by C. L. Parsons. 1912. 44 pp. 5 cents.

BULLETIN 63. Sampling coal deliveries and types of Government specifications for the purchase of coal, by G. S. Pope. 1913. 68 pp., 4 pls., 3 figs. 10 cents.

BULLETIN 70. A preliminary report on uranium, radium, and vanadium, by R. B. Moore and K. L. Kithil. 1913. 100 pp., 2 pls., 2 figs. 15 cents.

BULLETIN 73. Brass furnace practice in the United States, by H. W. Gillett. 1914. 298 pp., 2 pls., 23 figs. 45 cents.

BULLETIN 88. The condensation of gasoline from natural gas, by George A. Burrell, Frank M. Seibert, and G. G. Oberfell. 1915. 106 pp., 6 pls., 18 figs. 15 cents.

BULLETIN 100. Manufacture and uses of alloy steels, by H. D. Hibbard. 1915. 77 pp. 10 cents.

BULLETIN 104. Extraction and recovery of radium, uranium, and vanadium from carnitote, by C. L. Parsons, R. B. Moore, S. C. Lind, and O. C. Schaefer. 1915. 124 pp., 14 pls., 9 figs. 25 cents.

TECHNICAL PAPER 1. The sampling of coal in the mine, by J. A. Holmes. 1911. 18 pp., 1 fig. 5 cents.

TECHNICAL PAPER 3. Specifications for the purchase of fuel oil for the Government, with directions for sampling oil and natural gas, by I. C. Allen. 1911. 13 pp. 5 cents.

TECHNICAL PAPER 23. Ignition of mine gas by miniature electric lamps with tungsten filaments, by H. H. Clark. 1912. 5 pp. 5 cents.

TECHNICAL PAPER 26. Methods for the determination of the sulphur content of fuels, especially petroleum products, by I. C. Allen and I. W. Robertson. 1912. 13 pp., 1 fig. 5 cents.

TECHNICAL PAPER 27. Monthly statement of coal-mine accidents in the United States, January to August, 1912, and statistics for 1910 and 1911, compiled by F. W. Horton. 1912. 24 pp. 5 cents.

TECHNICAL PAPER 60. The approximate melting points of some commercial copper alloys, by H. W. Gillett and A. B. Norton. 1913. 10 pp., 1 fig. 5 cents.

TECHNICAL PAPER 90. Metallurgical treatment of the low-grade and complex ores of Utah, a preliminary report, by D. A. Lyon, R. H. Bradford, S. S. Arentz, O. C. Ralston, and C. L. Larson. 1915. 40 pp. 5 cents.

TECHNICAL PAPER 109. Composition of the natural gas used in 25 cities, with a discussion of the properties of natural gas, by G. A. Burrell and G. G. Oberfell. 1915. 22 pp. 5 cents.

INDEX.

A.	Page.	Page.	
Accidental mine, Ariz., wulfenite in.....	52	Canada, molybdenite in, production of.....	34
Achrematite, composition of.....	7, 14	molybdenite from, results of concentration of.....	104
occurrence of.....	14	Carpenter, —, on properties of molybdenum steel.....	23
tests for.....	14	Catherine's Hill, Me., occurrence of knightite at.....	17
Alaska, molybdenite in.....	86	Chemical reagents, manufacture of, use of molybdenum in.....	20
results of concentrating.....	104	Chico, Mont., molybdenite near, view of.....	73, 74
Alloy steels, molybdenum in, value of.....	20, 21, 25	Chihuahua, Mexico, achrematite in.....	14
uses of.....	20	Climax, Colo., molybdenite near.....	63, 68, 69
See also Alloy steels named.		Coblentz, W. W., determination of emissivity of molybdenum by.....	18
Ammonia, production of, use of molybdenum in.....	28	Colett, E., on determination of molybdenum.....	43
Ammonium molybdate, use of.....	28	Collins mine, Ariz., buildings of, view of.....	46
Andrews, E. C., on molybdenum in New South Wales.....	31	description of.....	46, 48
Arizona, molybdenum ores in.....	45, 52-58, 86	situation of, map showing.....	46
See also Localities and mines named.		Concentration of ores, tests of.....	91, 92
Armor plate, use of molybdenum in.....	26	wulfenite in.....	46, 47
Arsenic in molybdenum ore, effect of.....	37	Colorado, molybdenum ore in, map showing.....	45, 63-72, 86, 89
Aspen, Colo., molybdenite near.....	71	view of.....	66
Austria, molybdenum ores in.....	14, 16	See also localities and mines named.	
B.		Colorado bureau of mines, acknowledgment to	6
Baringer Hill, Tex., powellite at.....	14	See also Molybdenite; Wulfenite; and methods named.	
Belonesite, composition of.....	7, 13	Concentrator, for water flotation.....	102, 103
occurrence of.....	13	results of tests with.....	98, 99
tests for.....	13	Concunully, Wash., molybdenite near.....	85
Bennett mine, N. Mex., wulfenite in.....	77	Connecticut, molybdenite in.....	86
Benton mine, Ariz., molybdenite in.....	58	Cooke, Mont., molybdenite near.....	76
Bibliography.....	121-125	Cooper, Me., production of molybdenum at.....	32, 93
Bismuth in molybdenum ore, effect of.....	37	Copper in molybdenum ores, objections to.....	37, 108
Blair, Thomas, on molybdenum in steel.....	21	removal of.....	108, 109
Boericke, E. R., acknowledgment to.....	6	Copperville, Ariz., molybdenite near, ore from, production of.....	52, 55
Borchers, W., on acid-resisting steels.....	25	view of.....	33, 105
Boykin, R. O., production of molybdenum by.....	33, 50, 116	Cordite, use of molybdenum in.....	28
Boykin & Hereford mill, Ariz., flow sheet of, figure showing.....	117	Corinthia, ilsemannite in.....	13
operation of.....	117, 118	Cornu, F., on occurrence of jordisite.....	9
tailing piles, view of.....	114	Corona, Cal., molybdenite near, ore from, view of.....	62, 60
view of.....	114	Cotopaxi, Colo., molybdenite near.....	70
See also Mammoth, Ariz., mill at.		Cripple Creek district, Colo., molybdenum minerals in.....	13, 16
Breckenridge, Colo., molybdenite near.....	63, 67	Crook A. R., on minerals associated with molybdenite.....	9
Bromide, N. Mex., molybdenite at.....	77	Crown Point mine, Wash., description of.....	79-83
Buchanan, Paul, cited.....	62	molybdenite in, cost of mining.....	82
Bureau of Mines, determination of molybdenum by.....	44	view of.....	8, 80
investigation of.....	3, 4	production of.....	32, 33, 82
Bureau of Standards, on melting point of molybdenum.....	17	situation of, map showing.....	80
Burgess, G. K., determination of emissivity of molybdenum by.....	18	Cutter, N. Mex., production of wulfenite from.....	34, 78
C.			
Cohen, Edward, on occurrence of jordisite.....	9		
Caliente, Cal., molybdenite near.....	63		
California, molybdenum ore in.....	45, 58-63, 86, 89		
analysis of.....	12		
See also localities and mines named.			

D.	Page.	Page.	
Daily, G. H., acknowledgment to.....	6	GUILLET, Leon, on ratio of molybdenum to tungsten in steel.....	22
Dana, E. S., acknowledgment to.....	6	H.	
on composition of molybdenum ores..	10, 13, 17	Hall, M. C., cited.....	61
Debray, —, on fusibility of molybdenum ..	17	Hamburg mine, Ariz., wulfenite in.....	50
Defacqz, E., on specific heat of molybdenum ..	18	Hasselberg, B., determination of emissivity of molybdenum by	19
Dentistry, use of molybdenum in.....	20, 27	Haynes, Elwood, on molybdenum in steel alloys.....	26
Des Cloizeaux, Alfred, on occurrence of molybdenum.....	16	Head, R. E., acknowledgment to.....	6
Disinfectants, use of molybdenum in	20	Helvetica, Ariz., molybdenite near	56, 57
Doerner, H. A., acknowledgment to.....	5	ore from, view of	52
Dome, Ariz., wulfenite near	50	Hereford, F. H., production of molybdenum by	33, 116
Duquesne, Ariz., molybdenite at	58	Hess, F. L., acknowledgment to	6
Dyes, use of molybdenum in	20	cited.....	62, 93
E.		Hill, J. M., on molybdenite in Arizona.....	56, 58
Eckhardt, M., on determination of molybdenum	43	Hills, B. W., cited.....	17
Electric furnaces, use of molybdenum in	20, 27	Hillsboro, N. Mex., wulfenite at	78
Electric lamps, use of molybdenum in	27	Homestake, Mont., molybdenite from	32
Electrostatic methods of concentrations, apparatus for	96, 97	Hoover, T. J., on oil flotation processes ..	101, 105-107
costs of	100	Hortense, Colo., molybdate from, analysis of	12
factors governing	94, 96	I.	
limitations of	95	Idaho, molybdenite in	86
results of tests of	98-100	Idaho Springs, Colo., view of molybdenum mineral near	15
Elmore process, results of tests with	107, 108	Iddings, J. P., on molybdenite near Chico, Mont	73
Emigrant, Mont., molybdenite near	73	Ilsemannite, composition of	7, 12
Empire, Colo., molybdenite near	5, 63, 64-67	occurrence of	13
ore from, production of	33, 67	Iridium steel, analysis of	24
view of	60, 64	J.	
Eositite, composition of	7, 14, 15	Jacobson, R. C., analyses of molybdenite by	53
occurrence of	15	Jordisite, characteristics of	9
tests for	15	K.	
F.		Kellog, J. M., on wulfenite deposits	51
Farrington, O. C., acknowledgment to	6	Kelvin, Ariz., wulfenite near	51
Ferris, J. B., cited	63	Kithil, K. L., acknowledgment to	5
Ferromolybdenum, use of	39	Knight, O. W., discovery of knightite by	17
Ferrotungsten, prices for	101	Knightite, occurrence of	16, 17
Flotation processes, principles underlying		Kokomo, Colo., molybdenite near	72
See also Elmore process, oil-flotation; water-flotation.		L.	
Ford, W. E., acknowledgment to		Lamy, L., on prices for molybdenite concentrates	38
Forsythe, W. E., determination of emissivity of molybdenum by	19	Laney, F. B., acknowledgment to	6
France, demand for molybdenum in		on molybdenite deposits	15, 83
Frenzel, A. B., acknowledgment to		Lawrence, H. F., on molybdenite in Montana	74
Fusion method for determination of molybdenum		Lawns, Cal., molybdenite near	61
G.		Leader mine, Ariz., molybdenite in	56, 57
Germany, as market for molybdenum	35	ore from, view of	52
Giesen, Walter, on ratio of molybdenum to tungsten in steel	22	Leal, H., acknowledgment to	6
Gin, Gustave, on composition of molybdenum minerals	14, 16	Leviathan mines, Ariz., description of	52-54
Glazes, use of molybdenum in	20	molybdenite from, concentration of	54
Gleason, Ariz., wulfenite near	51	Lindgren, Waldemar, cited	13, 16
Gledhill, J. M., on properties of molybdenum steel	23, 24	Lively, C. S., acknowledgment to	6
Gold in molybdenum ore, occurrence of	11, 115	Loomis, Wash., molybdenite near	83
recovery of	115	workings of, view of	80
Gratacap, L. P., acknowledgment to	6	Lordsburg, N. Mex., wulfenite near	78
Great Britain, as market for molybdenum	35, 39	Low, A. H., cited	41
Guichard M., on specific heat of molybdenum	18	Lucky Bill mine, N. Mex., wulfenite in	78
		ore from, view of	10

M.	Page.		Page.
Magdalena, N. Mex., molybdenite at.....	77	Molybdite, view of	10
Magnet steel, composition of.....	25	Molybdoferrite, composition of	16
Maine, molybdenite in.....	86	Molybdurane, composition of	16
Mammoth, Ariz., wulfenite mill at, concentratates from.....	33, 118	Montana, molybdenite in.....	45, 72-77
operations of.....	5, 115-119	Moore, R. B., acknowledgment to.....	5
view of.....	6	Morgan, J. C., acknowledgment to.....	5, 41
<i>See also</i> Boykin & Hereford mill.		Myers, W. S., acknowledgment to.....	6
Mammoth mine, Ariz., buildings of, view of.....	46		N.
description of.....	46-48	Nathrop, Colo., molybdenite near.....	70
situation of, map showing.....	46	Nevada, molybdenum ores in.....	87, 89
wulfenite ore from, production of.....	32	New Hampshire, molybdenum ores in.....	87
view of.....	8	analysis of.....	12
Marble, Colo., molybdenite near.....	71	New Jersey, molybdenite in.....	87
Massachusetts, molybdenum ores in.....	86, 89	New Mexico, molybdenum ores in.....	45, 77-79
Melissa mine, Ariz., wulfenite in.....	50	New South Wales, molybdenum in, production of.....	5, 29, 31
Mendenhall, C. E., determination of emissivity of molybdenum by.....	18	New York, molybdenum ores in.....	87, 89
Merrill, G. D., acknowledgment to.....	6	Nogales, Ariz., molybdenite near.....	57
Metallic molybdenum, prices for, uses of.....	39	North Carolina, molybdenite in.....	88
Meyer, A. R., cited.....	17	Northrup, E. F., cited.....	28
Mickle, K. A., on flotation processes.....	101	Norway, molybdenum in, production of.....	5,
Minnesota, molybdenite in.....	86	29, 31, 32, 107	
Modoc mine, N. Mex., molybdenite at.....	77	O.	
Mohawk mine, Ariz., wulfenite in.....	51	Oak Springs, Nev., powellite near.....	14
Moissan, Henri, cited.....	16	Oil flotation, costs of.....	107
melting of molybdenum by.....	17	treatment of molybdenite ores by.....	106
on properties of molybdenum.....	17, 20	Oklahoma, molybdenite in.....	88
Molybdenite, composition of.....	7	Old Yuma mine, Ariz., description of.....	48-50
concentration of.....	91-93, 97-100	installation of mill at.....	5
results of.....	107, 108	production of molybdenum at.....	34, 111, 112
minerals associated with.....	9, 53,	Ophir, Mont., molybdenite near.....	69, 75
55, 65, 67, 68, 70-73, 75, 76, 78, 81, 83, 84, 86-88, 95		ore from, view of.....	74
mining of, costs of.....	54	Oregon, molybdenite in.....	88
occurrence of.....	8, 9, 58-76, 79-88	Organ, N. Mex., molybdenum deposits at.....	77
prices for, discussion of.....	38, 39	Oroville, Wash., molybdenite near.....	85
properties of.....	7, 101	Oscillating table, concentration of wulfenite	
tests for.....	8	ores on.....	112-114
views of.....	8, 52, 60, 64, 66	P.	
Molybdenum, characteristics of.....	17	Parkdale, Colo., molybdenite near.....	70
deposits of. <i>See</i> States and localities named.		Parsons, C. L., acknowledgment to.....	5
determination of.....	43	Patagonia, Ariz., molybdenum ores near.....	58
ductile, electrical resistance of.....	18	Pateraite, composition of	7, 14
duty on.....	34	Pennsylvania, molybdenum ores in.....	88
in steel, ratio of, to tungsten.....	22	Phoenixville, Pa., wulfenite from, analysis of.....	10
relative advantages of.....	5	Piranini, M. V., cited.....	17
market for, factors governing.....	3, 4, 35-37, 39	Plumb, A. M., acknowledgment to.....	6
melting point of.....	17	Pohnsdorf, A. G., acknowledgment to.....	6
precipitation of, methods for.....	42	Porvenir, N. Mex., molybdenite near.....	77-79
production of, in United States.....	32, 33, 36	ore from, production of.....	33
properties of.....	17-20	view of.....	74
recovery of, methods for.....	91-100	Powellite, composition of	7, 13
selling price of.....	4	occurrence of.....	14
solution of, methods for.....	41, 42	tests for.....	14
tests for.....	40	Powers, C. R., on wulfenite deposits.....	51
weighing of.....	43	Pratt, J. H., cited.....	32, 51
<i>See also</i> Metallic molybdenum and molybdenum minerals named.		Pulsator jig, concentration of wulfenite ores	
Molybdenum indigo, use of.....	28	on.....	111-114
Molybdenum tannate, use of.....	28	Pyrite in molybdenum concentrates, objections to.....	108
Molybdenum wire, tensile strength of.....	18	removal of.....	108, 109
Molybdenite, composition of.....	7, 11, 12	Pyrrhotite in molybdenum concentrates, objections to.....	108
occurrence of.....	11, 12		
tests for.....	12		

Q.	Page.	T.	Page.
Queensland, production of molybdenum in	5, 29, 30	Tailing piles, recovery of wulfenite from	116
R.		view of	66, 114
Radersburg, Mont., wulfenite near	72	Telluride, Colo., molybdenite from, analysis of	12
Randall, D. L., on volumetric determination of molybdenum	43	Texas, molybdenite in	88
Ransome, F. L., cited	13, 16	Tomasket, Wash., molybdenite near	83
Red Cloud mine, Ariz., wulfenite in	50	Tool steel, composition of	24
Red Mountain, Colo., molybdenite in	5, 63-67	cutting speed of	24
ore from, production of	33	molybdenum in	23
view of	64	<i>See also</i> Iridium steel.	
Rhode Island, molybdenite in	88	Troy, Ariz., wulfenite near	51
Ridley mine, Ariz., molybdenite in	57	Tucson, Ariz., molybdenum ores near	48, 50, 57
Risley, J. M., on molybdenite in Washington	84, 85	concentration of	5, 34, 111, 112
Robinson, Colo., molybdenite near	68-70	Tungsten in molybdenum ore, effect of	37
Robischaud, P., on molybdenite deposit in		in steel, ratio of molybdenum to	22
Washington	84	relative advantages of	5
Rociada, N. Mex., molybdenite at	77	selling price of	4
Rolling and screening, concentration by	93, 94	Tungsten wire, tensile strength of	18
Romero mine, N. Mex., molybdenite in	78, 79	Twin Bridges, Mont., wulfenite near	72, 76, 77
ore from, view of	74	U.	
Roscoe, H. E., on chemical properties of molybdenum	20	Umpleby, J. B., on minerals associated with molybdenite	9
S.		United States, molybdenum in, imports of	34, 35
Sackett, E. C., on molybdenite near Chico, Mont.	74	occurrence of	5, 86-90
St. Cloud, Colo., molybdenite near	72	production of	3, 4, 32-34
San Diego, Cal., molybdenite near	60, 61	<i>See also</i> States and localities named.	
ore from, concentration tests of	98	United States Geological Survey, on production of molybdenum	32
Santa Maria mine, Cal., molybdenum ore		Utah, molybdenum ores in	88-90
from, view of	8, 10, 60	V.	
Santa Rita, N. Mex., wulfenite near	78	Vail, Ariz., molybdenite at	57
ore from, view of	10	Vanadium, use of, in tool steel	24
Saxony, occurrence of jordisite in	9	Vermont, molybdenite in	88
Schaller, W. T., cited	11-13	Vulture mine, Ariz., wulfenite deposits in	52
Scheelite, occurrence of molybdenum in	17	W.	
Schorlemmer, C., on chemical properties of molybdenum	20	Waltenberg, R. G., determination of emissivity of molybdenum by	18
Schrader, F. C., on molybdenite in Arizona	56, 58	Warren, C. H., acknowledgment to	6
Schultz, Ariz., mine at, production of molybdenum from	32	Washington, molybdenite in	45, 79-85
view of	46	Water flotation, factors governing	102
Scotland, occurrence of eosite in	15	results of tests of	103-105
Shepard, F. E., acknowledgment to	6	Weed, W. H., on molybdenite in Montana	73
Skykomish, Wash., molybdenite near	85	Westcliffe, Colo., molybdenite near	71
Snyder, Ira, on molybdenite deposit in Colorado		Widmar, R. J. A., acknowledgment to	6
Sodium molybdate, use of		Wire, molybdenum, uses of	27
South Carolina, molybdenite in	88	Wolff, J. E., acknowledgment to	6
South Dakota, wulfenite in	89	Wood, H. E., acknowledgment to	6
South Hecla mine, Mich., powellite at	14	on water flotation	103, 104, 109
Steel, molybdenum, early objections to	21	Wootton, W. O., on occurrence of jordisite	9
effect of	22, 25	Wulfenite, composition of	7, 9, 10, 118
investigations of	21, 22	concentration of	92, 110-112, 114
manufacture of	22	minerals associated with	11,
<i>See also</i> Alloy steels; magnet steel; tool steels.		45, 46, 47, 49, 50, 75, 77, 89, 90	
Steel wire, tensile strength of	18	occurrence of	10, 45-52, 58, 63, 76, 77, 89, 90
Stellite, analysis of	27	production of, in United States	32, 33, 36
use of molybdenum in	26	tests for	10
Stoughton, Bradley, on composition of armor plate	26	views of	8, 10, 46
Sullivan, J. J., wulfenite sampled by	51	Wulfenite concentrates, prices for	38, 39
Swart, W. G., acknowledgment to	6	screen test of	119
Swinden, Thomas, investigations of molybdenum steel by	21	Wyoming, molybdenite in	88
		X.	
		X-ray tubes, use of molybdenum in	20
		Y.	
		Young, William, acknowledgment to	6

